GAIN BASED QUALITY COMPUTATION IN WDM ROUTING

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by

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CERTIFICATE

This is to certify that the thesis entitled, "**GAIN BASED QUALITY COMPUTATION IN WDM ROUTING**" submitted by AKANKSHYA BISWAL in partial fulfilment of the requirements for the award of Dual degree in **Electronics and Communication Engineering** with specialization in "**Communication and Signal Processing**" during session 2010-2015 at National Institute of Technology, Rourkela (Deemed University) and is an authentic work by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to an other university/institute for the award of any Degree or Diploma.

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ABSTRACT

In case of WDM networks, normally optical fibre cables are being used to transmit signal in the form of a light pulse within the transmitter and receiver. These systems possess the power to transmit more than one signal simultaneously. But we know light signal degrades in intensity when it travels through a long distance within the fibre. That is why it is essential to amplify the light signals together at a time after travelling a certain distance to regain the original one. In that case, Optical amplifiers are being used in order to amplify the light signals. There are various types of optical amplifiers exist. They are:–EDFA and Raman amplifier.

In this thesis, analysis of a WDM network is carried out taking into account EDF amplification with the help of opti system software. So to reduce the attenuation losses after a long distance transmission, optical amplifiers are used. Here the gain and noise figure of the EDFA with different pumping techniques is analysed value. After that, emphasis has been given on Raman amplifier and one mathematical model has been taken into consideration to calculate the gain. After that one WDM network having 10 nodes connected to each other bidirectional through Raman amplifier is taken in to account. Using that mathematical model, gain has been calculated for each path .for a given source and destination, possible paths are observed, gain is being calculated for each route and route with maximum gain is being considered as the best route for that source-destination pair. Blocking probability can be defined as the probability of call losses for a group of identical parallel resources. Here for a given wavelength number and a given load, blocking probability of each node is being calculated and analyzed how it varies when gain margin varies, also no of routes and no of wavelength.

LIST OF FIGURES

ACRONYMS

EDFA- Erbium Doped Fibre Amplifier

OFC-Optical Fibre cable

OF-Optical Fibre

WDM - Wavelength Division Multiplexing

Q-Factor - Quality Factor

SMF – Single Mode Fibre

SOA – Semiconductor Optical amplifier

SNR – Signal to Noise Ratio

NF – Noise Figure

IMM-Interactive Matrix Methodology

O-E-O- Optical-Electric-Optical

VPN-Virtual Private Network

OVPN- Optical Virtual Private Network

VC- Virtual Circuit

DWDM- Differential Wavelength Division Multiplexing

FWHM-Full Width at Half Maximum

TDM-Time Division Multiplexing

FDM-Frequency Division Multiplexing

WDM-Wavelength Division Multiplexing

CONTENTS:-

Chapter 1

Introduction

1.1Introduction

WDM optical systems are the upheaval in information transmission in view of low loss, fast and better data transfer capacity and high limit. So a ton of examination is going ahead in this field. Optical amplifiers are the foundation of optical system as they enhance the signal which happens because of the losses within fibre and numerous different reasons. EDFA is an optical amplifier which is the most utilized amplifier due to their high pick up and low pump power. So EDFA conduct in a WDM system needs to be contemplated. So in this venture EDFA gain and noise figure at distinctive pumping wavelength is examined.

Fibres additionally experience the ill effects of scattering because of fibre material nonlinearities and distances that signal goes inside the fibre. So this scattering must be minimized by a few times. Introducing the DCF fibres is one of the techniques to repay the scattering because of single mode fibres. The DCF have been analysed with different information rate and setups for characterizing the ideal results.

1.2Literature Survey

Performance Analysis of EDFA for different Pumping Configurations at High Data Rate by Prachi Shukla, Kanwar Preet Kaur defining different types of pumping techniques and gain and noise figure analysis with respect to fibre length.

Mathematical Model of Amplified Stimulated Raman Scattering and Fibre Raman Amplifier by Hani j. Kbashi , Mohammed A. Hameed, Amer A. Ramadan University of Baghdad, College of Science,2011 describing the gain calculation of a Raman amplifier and variation of gain with respect to fibre length.

Calculations and Measurements of Raman Gain Coefficients of Different Fibre Types Yukon Kang Roger H. Stolen, Chair, Ira Jacobs,Ahmad Safaai-Jazi December 9, 2002 Blacksburg, Virginia describing how the Raman gain coefficient with variation of pumping power and frequency.

Quality of service estimation Techniques for an optical virtual private Network over WDM/DWDM Network by Santos Kumar Das under the guidance of Prof. S. K. Patra, National Institute of Technology, Rourkela describing techniques of finding path on the basis of length.

Estimating the blocking probability in wavelength-routed optical by Luiz H.Bonani , Iguatemi E.Fonseca ,4th July,2013 describing how blocking probability is calculated and how it varies with respect to gain margin and no. of wavelength .

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1.3 Objective

- To study and explore the gain as well as noise figure of an EDFA at various pumping strategies using distinct pumping wavelengths and power. The various pumping systems are co pumping, counter pumping and bidirectional pumping.
- To analyze characteristics of Raman amplifier and calculate the gain using a mathematical model and observe the gain vs. fibre length
- An WDM network has been taken having 10 nodes and 21 links is taken .Using that mathematical model, gain is being calculated for all possible routes between a source and destination and the route with maximum gain is considered as the best path between them.
- Blocking probability is being calculated.

1.4 Thesis Overview

This thesis contains 4 chapters having introduction, working Model, results and conclusions.
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Chapter 2: Optical Fibre communication, which actually contains small introduction about optical fibre system for communication, its advantages, WDM network and also Optical amplifiers ,in addition to that analysis of gain as well as noise figure of EDFA using various pumping techniques.

Chapter 3: analyze the characteristics of Raman amplifier and calculate the gain using a mathematical model and observe the gain vs. Fibre length.

Chapter4: A WDM network has been taken having 10 nodes and 21 links is taken. Using that mathematical model, gain is being calculated for all possible routes between a source and destination and the route with maximum gain is considered as the best path between them. After that blocking probability is being calculated.

Chapter 2

Optical Fibre Communication

Introduction

Communication in its most basic sense transmission of information from sender to receiver through a medium. For data transmission, many mediums have been used by humankind. Coaxial cable was perhaps the most versatile transmission medium and had a strong influence on data transmission .Unfolded in 1940[2], the coaxial cable system was a 3MHz system which could over send more than 300 voice channels .High cable losses and repeater spacing makes coaxial cables for limited use and for longer transmission length these are very expensive .The discredits led microwave communication system transmit signals using electro-magnetic carrier waves in the range of GHz using different modulation techniques .Allowance of larger repeater spacing added to its distinction but microwave communication endured limited bit rate. Revolution of telecommunications was marked by the introduction of Optical fibre, which was developed in 1970s , and became the essence of Information era .Its fore deals over electrical transmission has let optical fibre replace copper wire communication in core network in today's world. High carrier frequency (~10THz) is used by optical communication system in near infrared or visible region in the electromagnetic spectrum. It became popular because it has high capacity bit rate and losses.

2.1 Optical Fibre Communication System

It has basic components :- the transmitter, the receiver and also the transmission path as drawn in the figure 2.1 [6].

There are 3 basic components in an optical fibre communication system namely the transmitter, the receiver and transmission path as displayed in the figure below [fig 2.1].

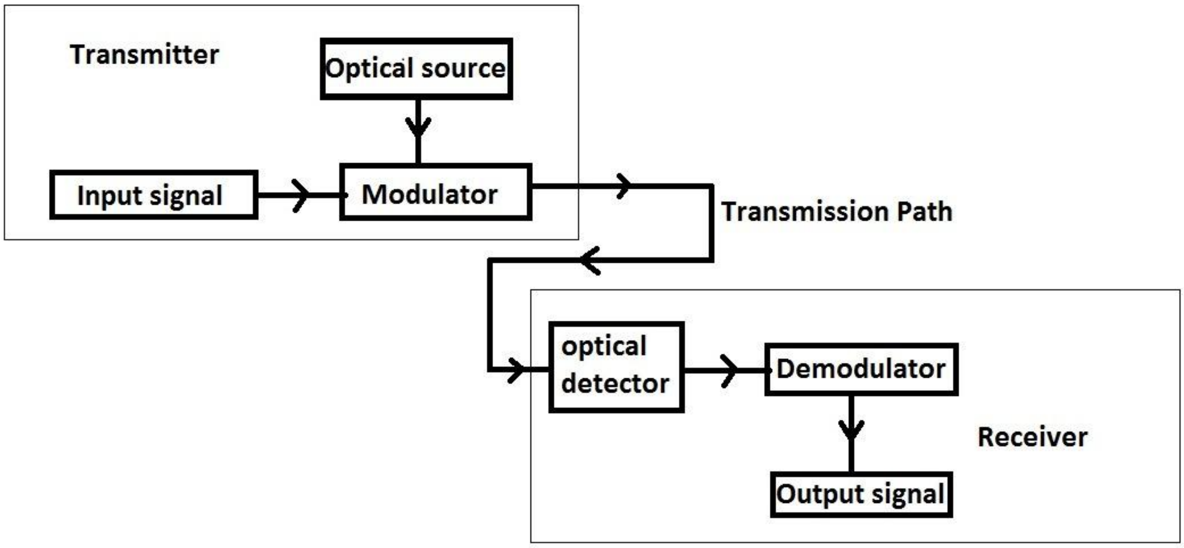


Fig 2.1 Optical fibre communication system

A data source generates an input signal in the transmitter side. One laser source is being used as optical source that can generate optical signal of certain wavelength. An optical fibre which takes electrical signal as input, convert them to optical signal, is one thin flexible filament made up of silica glass. The optical signal is carried along the length of fibre and is reconverted to electrical signal at the receiver end.

The optical signal and the data source both are fed to the modulator and the outcome modulated signal which an optical fibre procreates when passing through the transmission path. At the receiver side, the optical signal is then being detected through an optical detector. To get the desired output the digital signal is then passed through the demodulator.

2.2 Advantages of optical fibre communication

- OFCs are usually cheaper than the conventionally taken wires.
- OFCs are not only has flexibility but also installed easily.
- In OFCs sign can engender longer distance transmission separations for example

50km or more than that (Single Mode fibre links) without any chance to recover that signal anyplace in between the source and destination.

- The OF links don't have speed impediments or data transfer capacity confinements. They can provide variable speed and data transfer capacity depending just on optics quality utilized at both.

- Optical fibre has resistance to fire.

- Optical fibre has an advantage where signals can travel long distance transmission like 50km or more without regenerating them anywhere in between.(Single mode fibre cables).

- Besides supporting Optics variable speed and bandwidth they also have a merit of not having any speed limitations or bandwidth limitations.

- Optical Fibre Cables bolster duplex interchanges, bidirectional transmission from Transmitter to Receiver and the other way around.

- Optical Fibre Cables don't experience the ill effects of Electromagnetic Interference as they convey light.

- For higher bandwidth and speed they are easily upgradable.

- They support bidirectional transmission, duplex communication from receiver to

  Transmitter and vice versa.

- They support a bandwidth up to 40Gbps to 100Gbps

- As optical fibres cables carry light that do not undergo Electromagnetic interference

- The probability of cross talk and hence signal losses are very less as compared to copper cables even if fibres run alongside each other.

2.3 Wavelength Division Multiplexing

An optical fibre material covers a considerably wide bandwidth of around 30THz. It would be a loss of bandwidth if a signal of 10MHz is used. To elude this problem, different techniques are being used for example: TDM and FDM. As it is very arduous to generate a signal of few femto seconds, multiplexing of signals in time domain is generally avoided. Big and large, for multiplexing signals, FDM is used. The evolution of Wavelength division Multiplexing technique has come up from FDM. Optical fibre in general can carry many light signals having different wavelengths concurrently.

Wavelength division multiplexing (WDM) is methodology of sending light signals of various wavelengths into a fibre simultaneously. WDM can be described as a technique which multiplexes many optical carrier signal by taking suitable wavelengths of Laser lights on a sole optical fibre to hold up different signals. Consequently there is an increase in capacity besides the bi-directional transmission along the length of the single fibre for the receiver and the transmitter.

2.4 Optical Amplifiers

Within an optical fibre a signal suffers from various defects like fibre losses due to attenuation , fibre Splice losses and also fibre tap losses .It becomes difficult to detect a signal due to these losses at the receiver end .Therefore it is imperative to compensate for the losses in the fibre if Transmission over long distance (over 100 km) .

Primitive technology included conversion of optical signals to electrical signals and then amplification followed by re conversion to optical signal which proved to be cumbersome and expensive process. After introduction of optical amplifiers in optical domain signal amplification was much easier as conversion to electrical signal was not necessary. The optical fibre communication field was revolutionised by the Optical amplifiers.

Basically there are 2 types of optical amplifiers:- fibre amplifiers and semi conductor opamplifier .Thereby optical amplifier was further subdivided into Fabry-perot semiconductor optical amplifier and Fabry-perot SOA and travelling wave SOA. Fibre amplifiers can be classified into EDFA, Raman amplifier and Brillouin amplifier. Fibre amplifiers are of 3 types Raman amplifier, erbium doped fibre amplifier, Brillouin amplifiers.

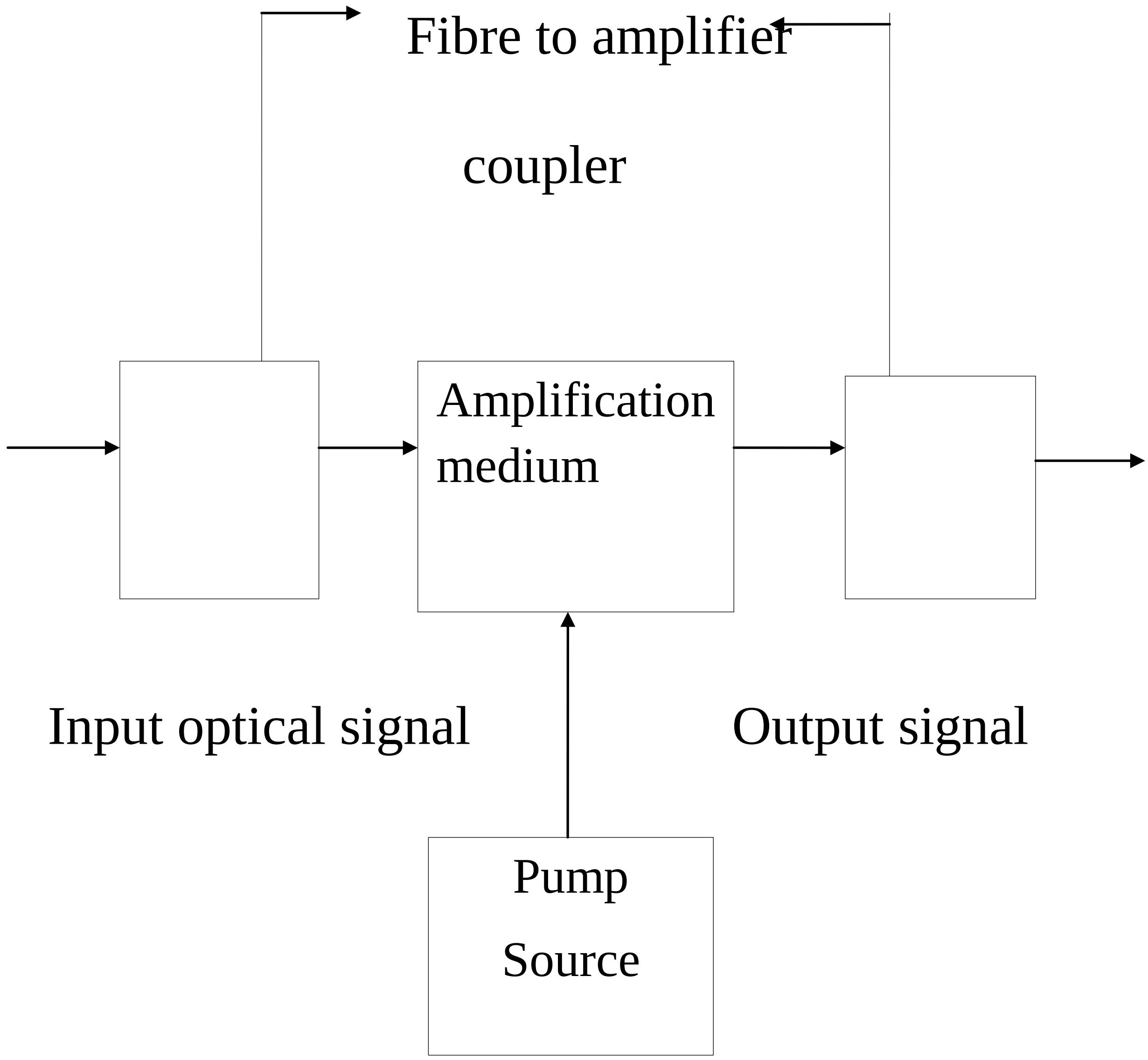


Fig 2.2 Block Diagram of basic optical amplifier

2.5 Application of Optical amplifier

2.5.1 In line Amplifier

Due to attenuation the signal suffers loss in single mode optical fibre. Thus there is need of frequent regeneration and amplification of signals after an interval of time. To compensate attenuation loss inline optical amplifiers are used which also increases distance with in regenerative repeaters.

2.5.2 Preamplifier

Before optical receiver, optical amplifier is being used in the form of a Front-end preamplifier. Besides, having high gain and better bandwidth the preamplifier amplifies the poor strength optical signals in order to minimise the SNR degeneration.

2.5.3 Power Amplifier

Just after the transmitter power or booster amplifiers are placed to boost the signals which help increasing the distance of transmission by 10-100km as far as fibre loss and gain is concerned.

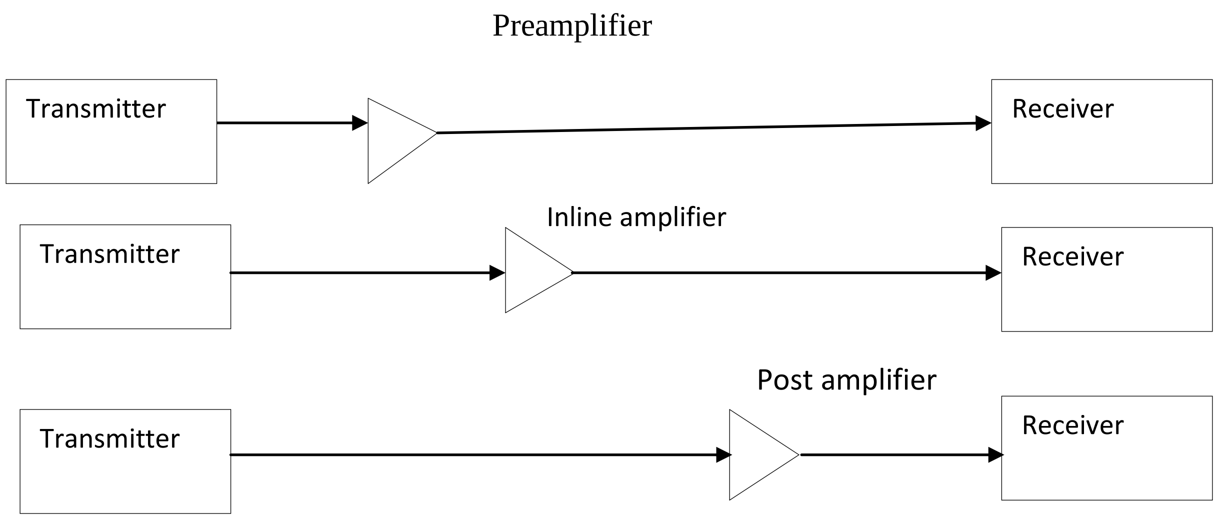


Fig 2.3 Block Diagram of various applications of optical amplifier

2.6 Erbium doped fibre amplifier (EDFA)

Erbium doped fibre can be described as a conventionally used silica based fibre which is being doped heavily with the use of active erbium ions as the gain medium. Basically Erbium ions (Er^{3+}) possess optical fluorescent properties which are suitable for (1500nm-1600nm), therefore it is so much effective in case of WDM to observe amplification. Basically EDFA[4] says when one optic signal for example signal of 1550nm wavelength enters in to the EDFA from the input, then that signal get combined with one 980nm or one 1480nm pump laser through wavelength division multiplexer device. Actually the input signal along with that pump laser passes through the fibre which is doped with erbium ions. In the end that 1550nm signal gets amplified due to interaction with the doped erbium ions. This can be understood properly in the diagram2.3.

. The 3 energy levels are respectively the ground level, the Meta stable level and the excited state level depicted as E1, E2, and E3 respectively in the figure. Let N1, N2, N3 denote the erbium ions population in the 3 levels respectively. In the equilibrium state, when no pump signal is used, the population density is as N1>N2>N3. There is a change in the population density level with the ion movement between the levels.

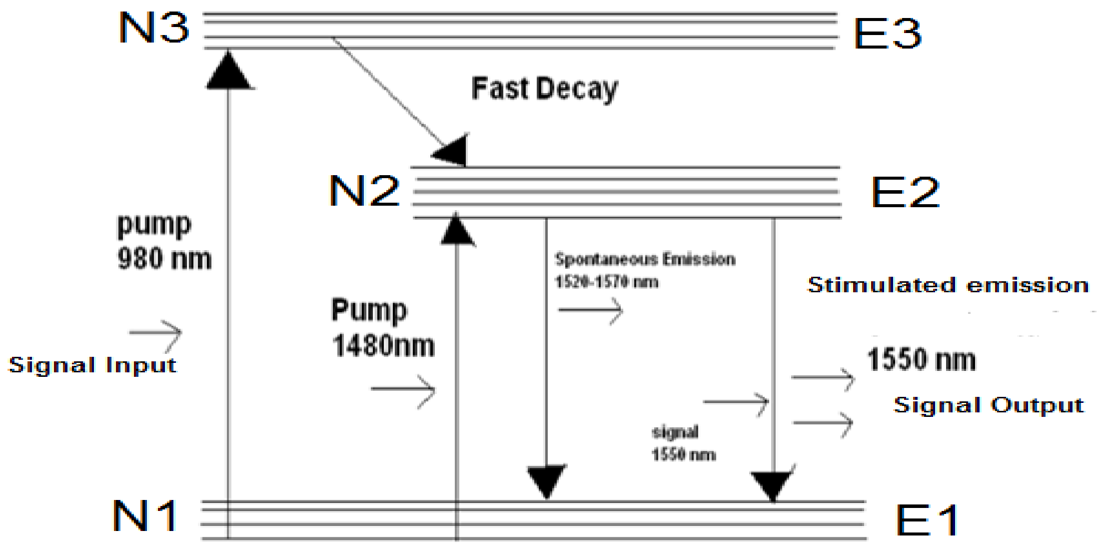


Fig 2.4 Energy diagram of three levels of Er^{3+} ions

With the application of pumping wavelength of 980nm ,the Er^{3+} ion present in ground phase (E1) get excited to another excited phase known as (E3). In general, the rate in which transition occurs from the ground phase to the new excited phase, actually depend on pumping power. Actually the particles which are present in the excited phase could not stay over there for more time and automatically it decays back to the state/phase of metastability and after that it falls back to ground phase after 10ms of time and then emits photon. So this process is known as spontaneous emission .If we think other side, the photons generated from spontaneous emission can be treated as noise because these photons are non-polarized and these are incoherent in space and time . In contrast when these ions / photons which are present in this meta stable state are injected with light photons having suitable wavelength, then they fall to an ground state by emitting photons of same frequency ,phase and polarization then travel in same direction as these incident wave photons . This process is called stimulated emission. Likewise in this procedure one photon gives two photons at the yield. Consequently duplication of photons happens and different number of photons subjected at the info produces huge number of photons at the yield which expands the light which we call as gain and then it amplifies the signal which was inputted. With 1480nm, the particles in the ground state energized straight forwardly to the meta-stable state and the above procedure happens. While the quantity of excited particles which are available in energized state/ meta stable state is more than the no of particles in ground state that happens to be called as population inversion technique.

2.6.1 Basic EDFA Design

EDFA stands for Erbium Doped Fibre Amplifier .It has Erbium doped fibre length , as pump a laser diode and a coupler which is wavelength selective that multiplexes or combines the signal wavelength and pump wavelength , as a result both can propagate together within the fibre. This signal and the pump both can propagate in same direction otherwise both simultaneously can propagate in opposite to each other direction inside an EDFA. In this paper types of pumping are discussed briefly. Actually the length of Erbium Doped Fibre cable depends on input power of a signal, pumping power, density of Er^{3+} ion and also the wavelength of pump and signal.

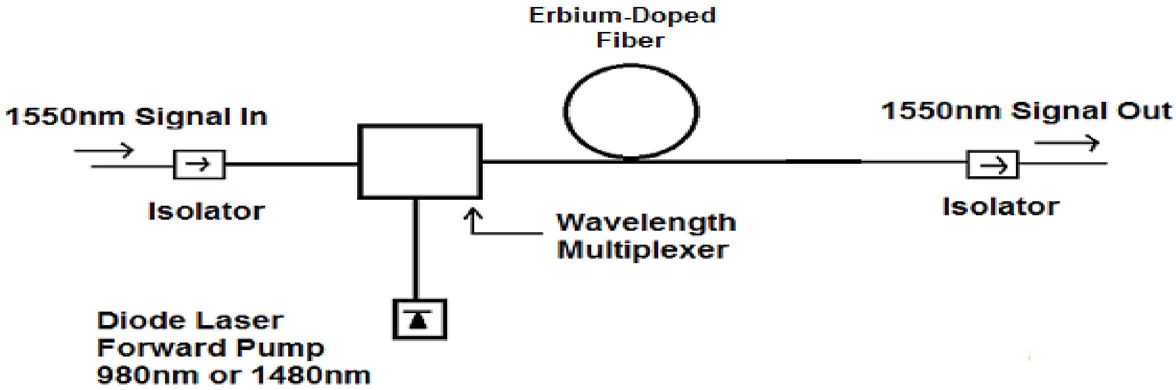


Fig 2.5 Block diagram of an EDFA

Fig 2.4 is a graph in which EDFA amplifier is co-pumped with laser. This data sent is of 1550nm wavelength optical signal. This optical signal is then being joined with a laser diode utilizing a wavelength multiplexer. At that point combined signal is being sent through an EDFA in which both the signals associate with particles of Er3+ and get to be excited .At keep going this process we would get an enhanced signal of the information we have given as 1550nm wavelength.

Analysis of Gain with Forward, Backward and Bidirectional Pumping Techniques

In this part we will investigate the assortment of Gain and Noise figure for EDFA with three types of pumping systems i.e. forward or Co-Pumping, Backward or Counter-Pumping and Bidirectional Pumping. Besides the diversity of gain [9] and NF is calculated for differing pumping wavelength and at distinct pumping power.

2.7 Introduction:

EDFA has assumed an immensely essential part in the optical fiber correspondence frameworks. Losses due to propagation are the greatest concerns to be taken care of toward optical fibres. Be that as it may, utilization of EDFA has helped gigantically in remunerating misfortunes. For wavelength division multiplexing frameworks EDFAs are greatly helpful on the grounds that they give uniform increase more than an extensive variety of wavelengths. EDFAs have pick up in the scope of 40–50 dB. The addition relies on upon different parameters like doping fixation, dynamic fiber length, pump force, center span, erbium range, numerical gap, sign data force, signal transfer speed, pumping wavelength [5]. The EDFAs are pumped with laser diodes at a pumping wavelength of 980nm or 1480nm. There are diverse pumping procedures utilized for EDFAs which are clarified in the following segment. The EDFA addition is one of the vital elements for WDM systems furthermore the commotion figure which characterizes the measure of clamor which is gathered. Here in this part the examination of the addition and commotion figure for distinctive pumping methods is finished.

2.8 Pumping Techniques

There are 3 ways in which we can pump the Er^{3+} ions present from its ground state to upper meta stable states.

1) Forward Pumping technique / Co-directional Pumping technique
2) Backward Pumping technique / Counter-directional Pumping technique
3) Bi-directional Pumping technique

2.8.1 Forward Pumping

In this technique, the inputted sign and the pumping sign both can spread together in same direction inside of a fiber. This inputted data and pumping signal are multiplexed utilizing a pump combiner/ wavelengths division multiplexer inside of the fiber the pump sign is consolidated with the inputted sign and after that the sign get enhanced with the use of an amplifier. Isolators are being utilized to verify that these signals would go in one direction just and no feedback of this signal will happen.

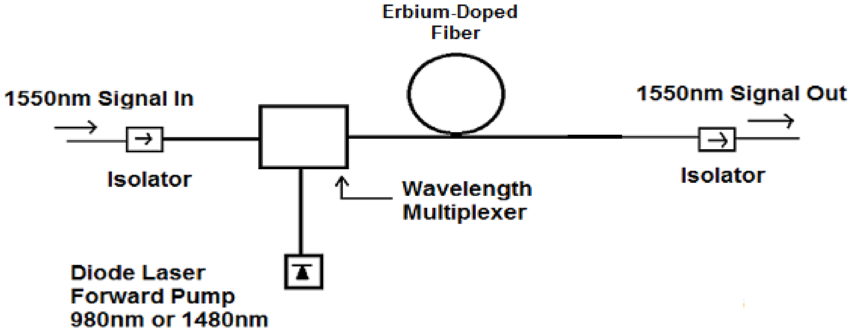
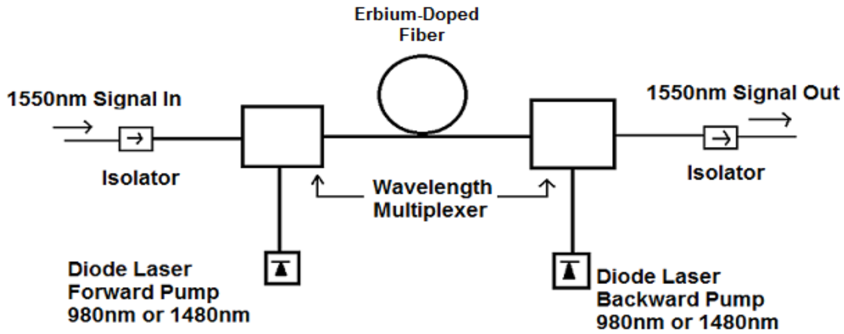


Fig2.6 Forward Pumping or Co-directional Pumping

2.8.2 Backward Pumping

In this type of technique, the inputted signal and the pumping signal both propagate in direction opposite to each other within the fiber. For the purpose of amplification actually the direction of inputted signal and pumping signal is not necessary. Actually they can pass in any direction.

Fig 2.7 Backward Pumping or Counter-directional pumping



2.8.3Bidirectional Pumping

In this type the inputted signal passes in 1 direction. But along with that there are 2 pumping signals which move inside the fibre. In this case, one pumping signal travels along the inputted signal and another one travels in direction opposite to the inputted signal.

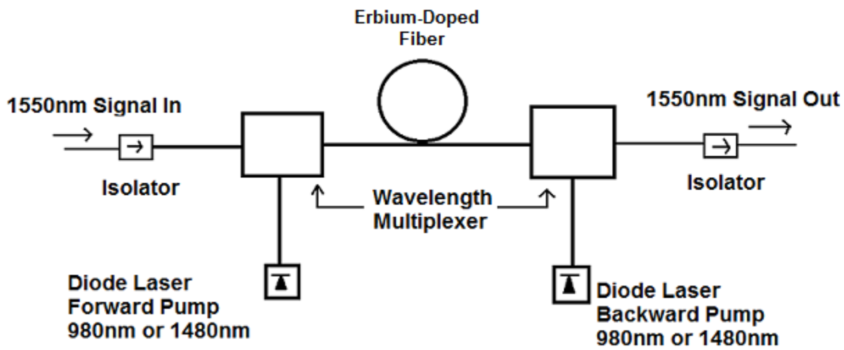


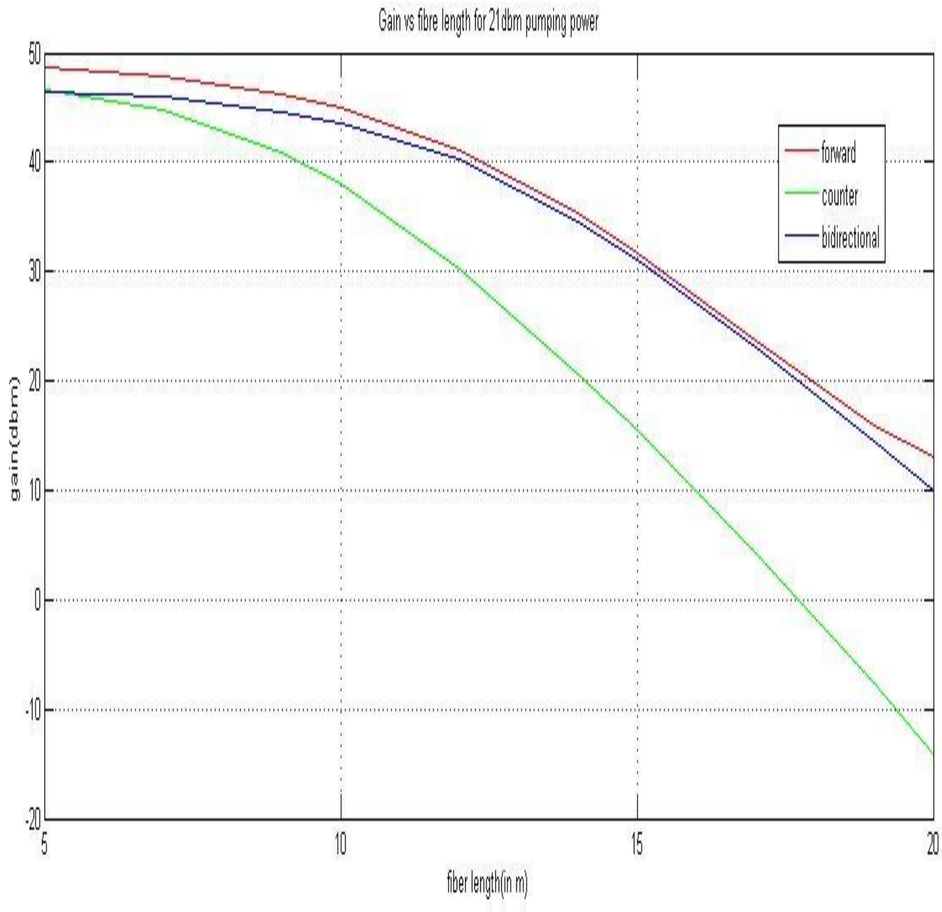
Fig 2.8Bidirectional pumping mechanism

2.9 Simulation Result and discussion

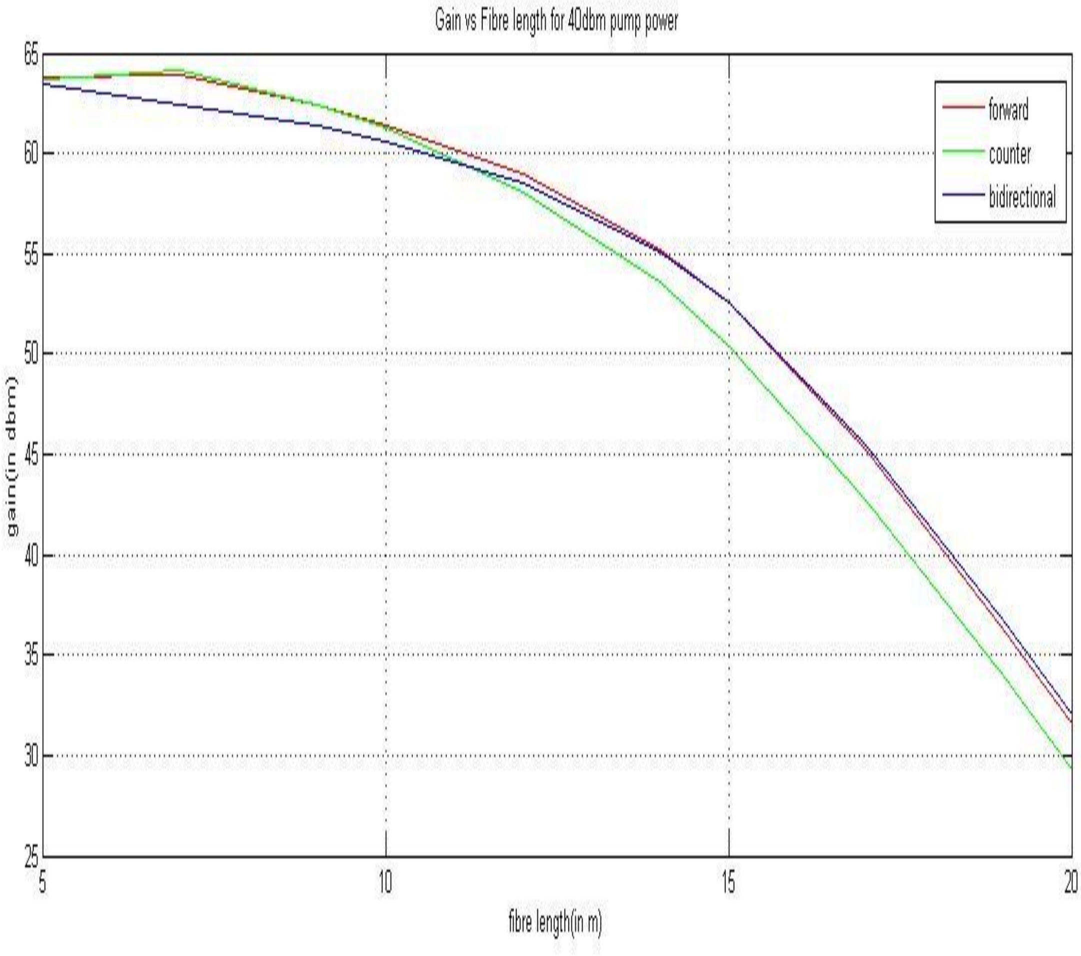
Gain VS Fibre length

Here taking 20dBm as pump power, and keeping that constant gain is being calculated for different fibre lengths starting from 1km to 20km and gain VS fibre length is being plotted for three different techniques and compared with each other. From this plot in fig2.9, gain decreases as length increases. The rate of decrease is highest for backward pumping and then bidirectional pumping and then forward pumping.

Similarly another case has been taken by taking pumping power as 40 dBm and gain VS fibre length has been plotted in fig2.10 by varying fibre length from 1km to 20 km. Here the behavior of the three plots (forward, bidirectional, backward) is same as in the 21dBm plot. But as the pumping power increases, range of gain increases.



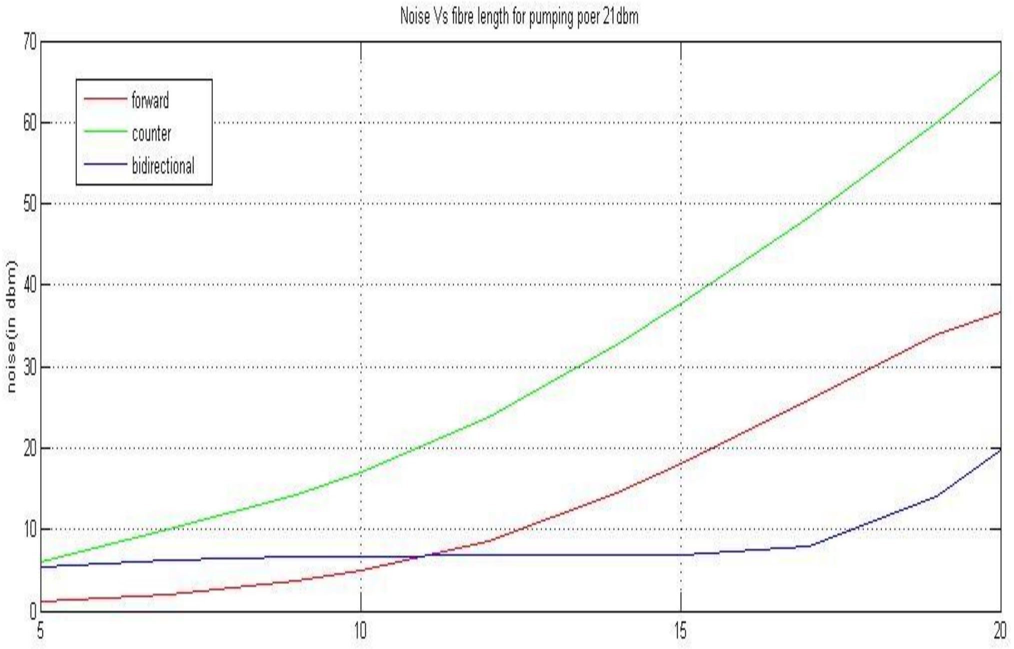
(Fig 2.9)



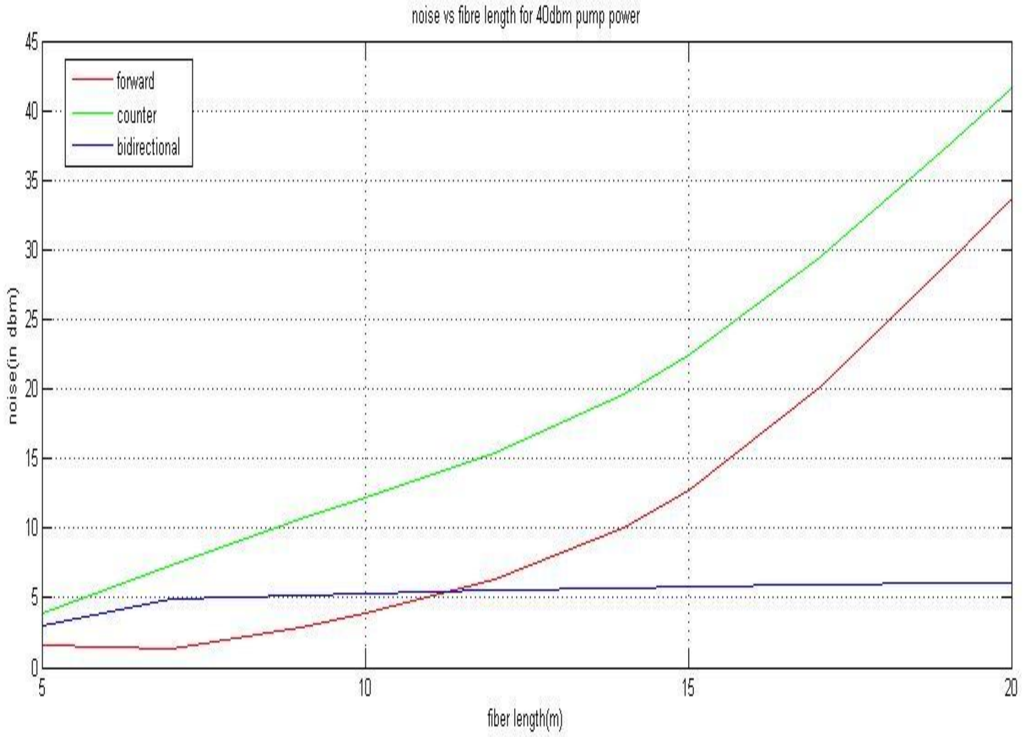
(fig 2.10)

Noise VS fibre length

Applying the same technique as above, initially noise is being calculated by varying fibre length and keeping a pumping power 21dBm constant and plot has been shown in fig2.11. As the length increases, noise increases simultaneously. The noise figure is maximum for backward then forward and least for bidirectional pumping. After that as pumping power increases to 40dBm, noise decreases relatively and same three cases for three pumping techniques has been taken and for 40dBm, noise figure VS fibre length has been plotted in figure 2.10.



(fig 2.11)



(Fig 2.12)

Conclusion

In this third chapter, the changes of Noise figure and Gain were observed using different pumping techniques. In the end, we observed co-pumping technique is the most preferred one because it has high gain and along with that relatively low NF. In another hand, bidirectional pumping technique is considered to be the the most optimized and suitable technique to get high gain and least NF. Whereas counter pumping technique gives high gain and worst noise figure. We can work on different pump power and also pump wavelength to obtain gain as well as low NF. By increasing pump power gain increases. By increasing pumping power, noise decreases.

Chapter 3

Study of Raman amplifier

Raman fibre amplifier

3.1 Brief history of Raman fibre amplifier

The history of a Raman amplifier [8] continues for about three decades, it started when scientists did the fabrication of a silica fibre with low loss in the year of 1970. The progress happened in three stages —that is the 70s,then the 80s and in the end the 90s.Out of these stages each stage has some own special features which was determined by needs of optical fibre communication process where that works as a driving force. In the 70s, we already have, in the year of 1971 scientist Stolen et al introduced stimulated Raman emissions process with in a SMF fabricated by using Corning Glass process for the first time. Over all these years all the prospection of fibre communication was not clear and even no one has properly claimed optical fibre amplifiers. So in the end, proper attention was given to theoretical as well as experimental investigations done about starting from the phenomenon to construct Raman fibre laser of low threshold. All the results of stimulated Raman scattering as well as Brillouin scattering upon the capacity of handling power of fibre optical was according to theoretical view taken by Smith by neglecting depletion of pump power due to the stimulated process. Actually this type of approach was acceptable in case of fibres with high loss , available at that period of time .Then after exact measurements of Raman gain coefficient of a silica fibre was carried out .In short we can say these papers are based on the study of Raman spectra for different glasses. Also appreciable efforts were given towards the low-threshold tuneable amplifier development. The results were successful.

3.2Significanceof Calculation and Measurement of Fibre Raman Amplifier

Fibre Raman Amplifier (FRA)[3,4] utilizes the transmission line as the Raman gain medium. It is another and promising innovation which can take the whole deal correspondence frameworks to another level through and through, particularly on account of Wavelength Division Multiplexing (WDM), which utilizes concurrent amplification of multi-channel light wave signals. It can likewise be utilized for repeater-less transmission, which utilizes optical gain as a compensation for the fibre loss. FRA is utilized to enhance the optical signal in optical fibre. It is taking into account the standard of exchanging force from the pump power to the input signal. This is done utilizing Raman cooperation in the middle of light and vibration modes of the glass. In combined silica the Raman gain coefficient increases at a Stokes movement of around 13.2THz with a 3dB transmission capacity which is around 6THz. The few components of FRA which attracts which are utilized as a part of transmission frameworks are as taken after.

1) **Simplicity of the amplifier architecture:** Raman gain can be obtained in any of the conventional transmission fibre. When the signals are launched high pump lasers are required. The added advantage is that in the absence of pump power there is no excess loss.

2) **Low noise:** Unlike the Erbium Doped Fibre Amplifiers (EDFA) which at least has a noise of 3dB, the distributed Raman Amplifier comes with the added advantage of delivering negative noise figures.
3) **Broad gain spectrum:** Wavelength division multiplexed system requires a broad gain bandwidth around 60nm in terms of FWHM. The Raman gain bandwidth is pretty much close to this. A unique technique is used for RFA i.e., by using multi-wavelength pump sources a broader gain spectrum is obtained.
4) **Flexible transmission window:** The operation window for FRA is adjustable because the pump wavelength controls the gain spectrum.
5) **Higher saturation power:** When compared with EDFA which has a saturation power around 50mW, the commercial Raman amplifiers are advantageous because they have a saturation power over 100mw.

	PUMP POWER	BANDWIDTH	SATURATION POWER	NOISE
EDFA	35mW	37nm from 1528-1565 with flattening technology	50mW	5.5dB
FRA	~350mW	100nm from 1520-1620 with 4 pumps		-2 dB(C band) -3 dB(L band)

3.3 Overview of Raman Scattering

Raman Scattering can actually be broadly divided into two categories: (a) Spontaneous Raman Scattering (b)Stimulated Raman Scattering. The current section provides a review of the history and principle of Raman Scattering.

3.3.1Spontaneous Raman Scattering

The basic principle of operation is that when one incident light possessing frequency of ν_0 is scattered from the molecules of a substance, the frequency of light scattered light will almost be same as the frequency of the light which was incident. Low intensities of light which either have a higher frequency or lower frequency than the incident light can also be observed is this process. This effect is known as as SRS [8]. This was discovered independently but simultaneously by Landsberg, Mandelstam and Raman in the year 1928.

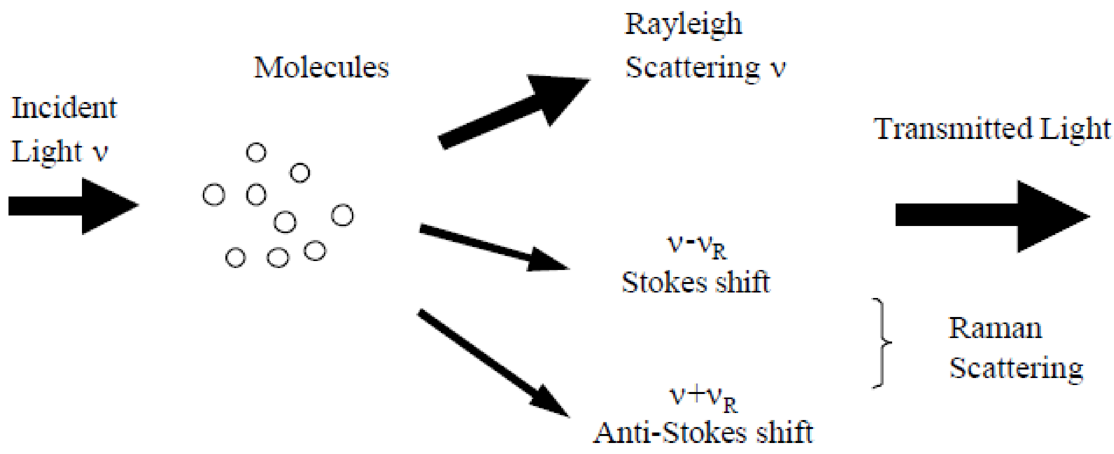


Fig3.1 Spontaneous Raman scattering

As depicted in the above figure, when one photon possessing frequency ν_0 falls upon a molecule with some random vibration state, then it excites the particle to an intermediate state; then the molecule immediately relaxes its energy state by emitting a photon. That molecule can also go to another higher vibration energy phase than the one before. Thus the resulting scattered light will possess lower energy than the incident light *(hns<hni)*; This effect is known as Stokes scattering. If the molecule was already present in an excited vibrational state, the light which is scattered will possess a higher energy *(hns>hni)* to form an anti-Stokes side band. This SRS effect is very useful and powerful tool to study the vibrational modes of all the forms like:-solids, liquids, gases. As fused silica and GeO2 have an amorphous nature, they exhibit a broad gain spectrum over the range 20THz.The Raman gain spectra in GeO2 and fused silica are being shown in Figures below. The two curves depicted in each of the figure shows the scattering of light that is parallel or perpendicular to the polarization of the light which excited the molecules. The comparison between perpendicular gain coefficients and the parallel ones reveals that the gain in former is much less than the later in fused silica and GeO2[19]

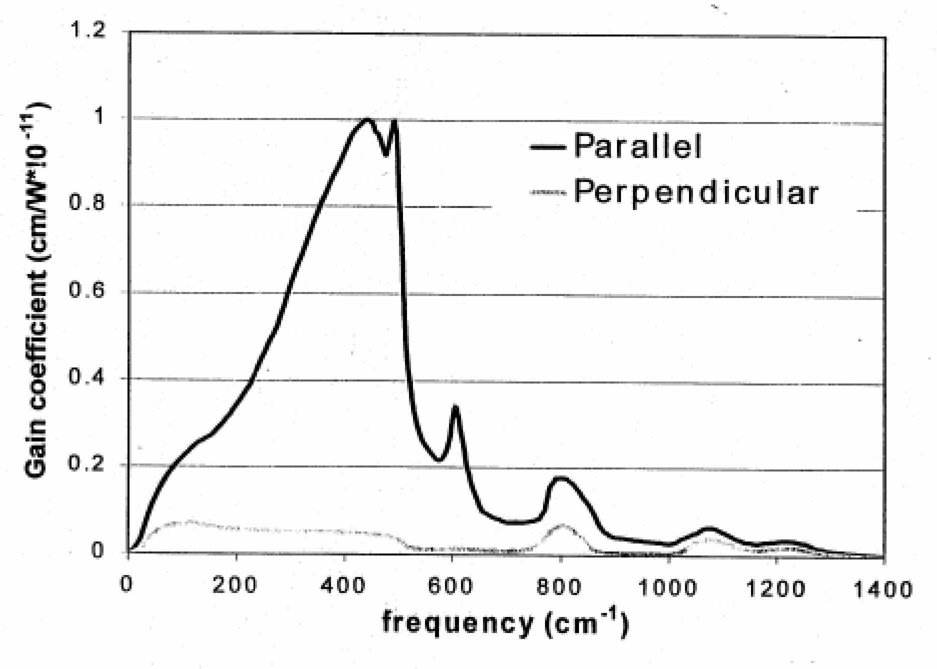


Fig 3.2 Gain coefficient VS frequency

3.3.2Raman Amplification using Stimulated Raman scattering

If a weaker signal at stokes frequency is sent along with a stronger incident beam which is called a pump, it stimulates the Raman scattering effect. This phenomenon is known as stimulated Raman scattering. This leads to the Raman amplification of a weaker signal at the expense of the stronger incident pump. The schematic diagram of the working of Raman amplifier is depicted in Fig. below. It can be seen from the figure that there are these kinds of pumping. First is co-directional pumping i.e., the pump light is coupled into the transmission either in the same direction as the transmission signal. Second is contra directional pumping in which the pump light is coupled into the transmission either in the opposite direction as the transmission signal else we can use both as shown in the figure.

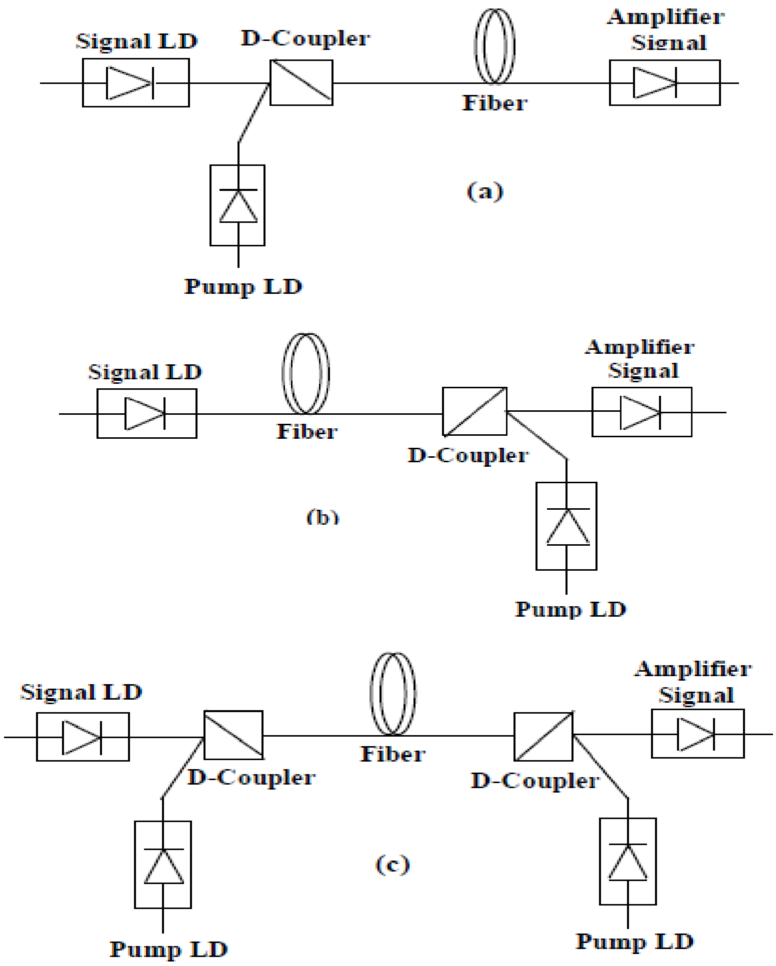


Fig3.3 (a) (b) (c) pumping techniques in Raman amplifier

3.4 Mathematical Model

Optical amplification via Raman amplification has several advantages. Some of them are a broad bandwidth; self-phase matching between the signal and the pump etc. When we launch a weaker signal along with a comparatively stronger pump, it will get amplified due to the SRS effect. The nonlinear interaction between the pump and stocks waves of SRS, considering a continuous wave (CW) or quasi-CW condition is governed by the following[11,8]:-

$$dI_s/dz = g_R I_P I_S - \alpha_s I_s \quad (1)$$

$$dI_p/dz = -(\omega_{p/}\ \omega_s) \times g_R I_P I_S - \alpha_p I_s \quad (2)$$

Where I_p, Is, a_p, ω_p, ω_s are the intensity, the attenuation and frequency of the pump and the signal waves respectively. Pump and signal beams are injected in to the fibre through a wavelength division multiplexing (WDM) fibre coupler at different frequencies ω_p, ω_s respectively. A coupler is a device with three or more fibres which are interconnected to provide mutual coupling between them.

Equation (2) can be easily solved if first term on its right hand side is neglected .This component is responsible for depletion of pump. If the solution is being substituted in equation 1, the equation obtained will be:

$$dI_s/dz = g_R I_0 \exp(-\alpha_p Z) I_s - \alpha_s I_s \qquad (3)$$

Where I_o represents the pump intensity at Z=0 which is incident, and g_R represents the Raman gain coefficient. Value of g_R is directly dependent on the wavelength of pump.

Equation (3) can be readily solved, and the result obtained will be

$$I_s(L)=I_s(o)\exp(g_R I_o L_{eff} - \alpha_s L) \qquad (4)$$

Where L represents the fibre length. The effective length of the fibre is given as follows:

$$L_{eff} = (1-\exp(-\alpha_p L)) / \alpha_p \qquad (5)$$

Because of pump absorption, the effective length of the fibre becomes L_{eff} instead of the actual fibre length which is L. If the length is short, the effective length is approximately equal to L, and if the length is long, it reaches $1/\alpha_p$. Clearly, high Raman gain can be achieved with the use of the following: high pump power, small effective area, long effective lengths, high stimulated Raman scattering gain coefficients. Along with this we need low signal and pump attenuations.

The Raman amplification gain can be easily obtained from equation (4). Assuming that the intensity of signal is much smaller than the pump intensity, the Raman amplification gain is given by the following equation:

$$G_A=\exp(g_R P_o L_{eff} / K A_{eff} - \alpha_s L) \qquad (6)$$

Where P_o represents the pump power, A_{eff} represents the effective core area of the fibre, and K represents a numerical factor which accounts for the polarization scrambling between the

optical pump and signal.
In conventional single mode fibre K=2For complete polarization scrambling.
Taking the log on both sides of the equation we obtain gain in DB scale as follows:-

$$G=4.34\ [g_R P_o L_{eff}\ /KA_{eff}] \tag{7}$$

Signal gain G in dB is dependent on the pump intensity, the effective length, the effective Raman gain coefficient, and the polarization state. The net Raman gain is a combination of the parallel and perpendicular gains because the polarizations of the pump and signal vary arbitrarily along the fibre. This is represented by a polarization factor K. The polarization factor is 1 if the pump and signal waves are matched in polarization else it is 2 if depolarized.

3.4.1 Calculations of Raman Gain and Raman Gain Coefficients

As discussed above a weak Stokes signal which is launched into the fibre with a stronger pump will be amplified because of SRS [7]. The amplification of the signal can be described via the following equations:

$$P_s(L)=P_s(0)\ \exp((g_R(\nu)P_0L_{eff})/KA_{eff}) - \alpha_s L) \tag{8}$$

$$g_{R(}\nu)=\sigma_0(\nu)\ .\ (\lambda_s^{\ 3}/c^2h\ n(\nu)^2) \tag{9}$$

Where c represents the velocity of light, h represents Planck's constant, $_s\, l$ represents the Stokes wavelength, n (v) represents the refractive index, which is dependent on frequency, and K represents the polarization factor. The ratio of radiated power at the Stokes wavelengths to the pump power at temperature 0K defines the spontaneous zero Kelvin Raman cross section $\sigma_0(v)$ s. This can be obtained with the thermal population factor

$N\,(v, T\,)$ and the Raman cross-section $\sigma_T(v)$ at temperature TK .

Simulation result and discussion

Here gain has been calculated by applying the formula from equation no (7) taking pump power as 0.5 dBm and Raman gain coefficient value as 3.8×10^{-3}.Value of A_{eff} has taken to be $6.3\times10^{-6}m^{2}$.The value of two attenuation constants are 0.5 respectively.

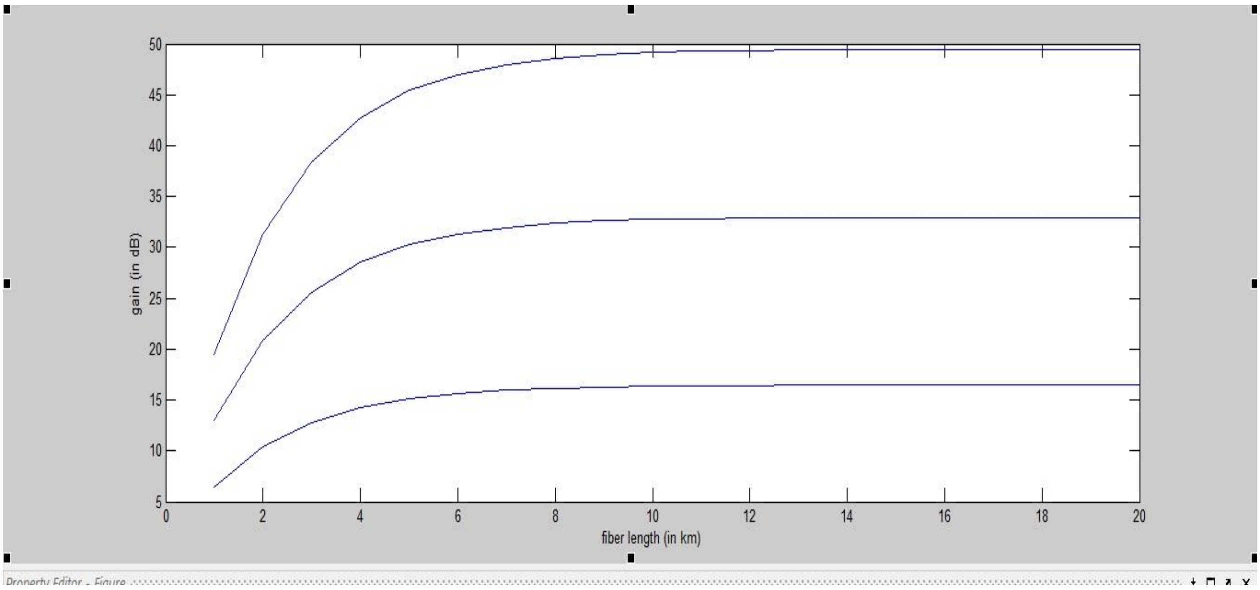


Fig3.4 gain VS fibre length

3.5 Conclusion

From this graph it is being proved that Raman gain increases as the length of fibre increases but after around 3km it reaches saturation level after that it started to decrease. Moreover, from this it is proved that higher Raman gains can be achieved by applying high pump power also fibre with lower loss. Followings are the comparisons between Raman amplifier and EDFA.

- Raman Amplifiers work on the principle known as stimulated Raman Scattering mechanism which is a considered to be a nonlinear process that is opposite to EDFA which has actually a linear effect.
- EDFA gives better output SOA in the form of Bit Error rate and output power in other hand it has non uniform gain spectrum.
- Raman gain amplifiers have better output in the case of amplification in L-band. Along with that flattening of gain issue as it has the ability to reduce impact of nonlinearity of fibre.

Chapter 4

WDM networking and Routing

4.1WDM/DWDM network

In case of an optical WDM or DWDM network, no optical to electrical and electrical to optical conversion of information happens in between intermediate routers, it reduces the burden on electronics. If there is an occurrence of Optical systems administration fit for giving a greater number of capacities than simply just a point-to-point correspondence. Commonly the data transmission that an optical system cans do backing is in the order of Tera bits every second (Tbit/s). In any case, the hardware system accessible today cannot prepare this high information rate offered by optical system. Cutting edge frameworks can deal with up to 160 wavelength channels and in this manner grow an essential 10 Gbit/s framework over a solitary fibre pair to more than 1.6 Tbit/s. In original systems, the gadgets at a switch/router took care of the information planned for it as well as controlled the traffic. This builds the weight on the hidden hardware. To completely use the accessible transmission capacity of an optical system, quicker electronic exchange working at Tera bit is needed. In any case, electronic circuits possess some of their own limitation and recent innovation licenses greatest speed in Giga bits range.

WDM/DWDM systems can possibly use the extremely great transfer speed of optical fibre and at lessened optoelectronic mismatch. WDM/DWDM systems are the second era optical systems, where information are steered through hubs (switches) in the optical area. It is of two sorts, for example, obscure and all optical system (straightforward). Misty system is utilized as a part of right on time stages, that devours more power. One additional issue with the systems is that, they are not versatile to fulfill upcoming requirments. These downsides can be overcome by straightforward systems, which are versatile with higher information conveying capacity and devour less power. This is attained to since, all-optical WDM/DWDM system reduces [13, 14] the changes in between optical and electrical energy

DWDM is the most creative and propelled innovation in fibre optic correspondence framework because of its potential capacity to give immense transfer speed over a single fibre cable [15]. DWDM innovation utilizes all the nearly divided wavelengths. Consequently, an extensive number of wavelengths can be multiplexed and prompting optical fibre to higher limit. One of the essential highlights of DWDM innovation is that, it can open up the whole wavelength all the while without even the need of O-E-O conversion and it can convey signal of different speed of light and transmits information at the same time through the optical fibre.

4.2 Gain Based Analysis

WDM divides the capacity of a single mode fibre in different channels, each using different wavelength. In a WDM network given a request, we need to setup a path between the source node and destination node. For a given request, that setting up a path is called routing. After setting up a path, wavelength is assigned to that path using different techniques (using converter or without converter).

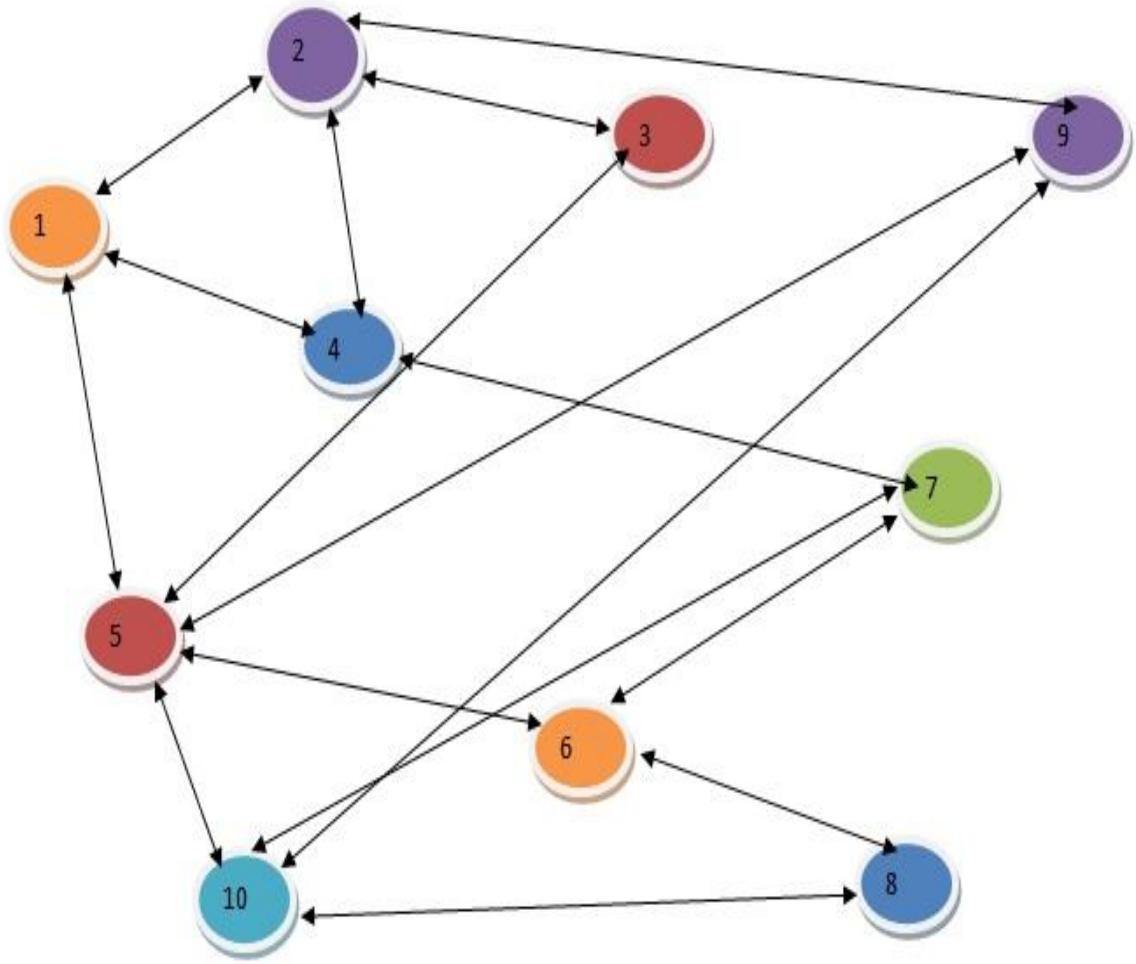


Fig 4.1WDM network structure

No of links	Source node	Destination node	Distance(in km)
1	1	2	70
2	1	4	70
3	1	5	140
4	2	3	70
5	2	4	140
6	2	9	280
7	3	5	140
8	4	7	140
9	5	6	70
10	5	9	210
11	5	10	210
12	6	7	70
13	6	8	70
14	7	10	140
15	8	10	70
16	9	10	70

Fig 4.2Distance between nodes

STEPS FOLLOWED

- Enter the source node from where you want to send signal and the destination node where you want to send to.
- Find the no of routes possible from source to destination.
- For each individual route if more than 1 links are there then
  - Find the gain for each link
  - The smallest gain among all links will be the gain of that route

- In this way calculate the gain of each route

- Sort the gain of all routes in descending order.

- The route with maximum gain will be chosen as the optimum path for data transmission between these 2 nodes.

Simulation results and discussions

Here we want to send signal from node2 to node3. For that all the routes possible between 2 and 3 has been calculated using DFS algorithm which is being shown below. After that gain is being calculated for each route and routes are being sorted in decreasing order of gain.

All possible routes for source as 2 and destination as 3

2	3	0	0	0	0	0	0	0	0
2	1	5	3	0	0	0	0	0	0
2	9	5	3	0	0	0	0	0	0
2	4	1	5	3	0	0	0	0	0
2	9	10	5	3	0	0	0	0	0
2	4	7	6	5	3	0	0	0	0
2	4	7	10	5	3	0	0	0	0
2	1	4	7	6	5	3	0	0	0
2	1	4	7	10	5	3	0	0	0
2	4	7	10	9	5	3	0	0	0
2	9	10	7	6	5	3	0	0	0
2	9	10	8	6	5	3	0	0	0
2	1	4	7	10	9	5	3	0	0
2	4	7	6	8	10	5	3	0	0
2	4	7	10	8	6	5	3	0	0
2	9	10	7	4	1	5	3	0	0
2	1	4	7	6	8	10	5	3	0
2	1	4	7	10	8	6	5	3	0
2	4	7	6	8	10	9	5	3	0
2	1	4	7	6	8	10	9	5	3
2	9	10	8	6	7	4	1	5	3

Sorted all possible routes based on gain margin

2	3	0	0	0	0	0	0	0	0
2	1	5	3	0	0	0	0	0	0
2	9	5	3	0	0	0	0	0	0
2	4	1	5	3	0	0	0	0	0
2	9	10	5	3	0	0	0	0	0
2	4	7	6	5	3	0	0	0	0
2	4	7	10	5	3	0	0	0	0
2	1	4	7	6	5	3	0	0	0
2	1	4	7	10	5	3	0	0	0
2	4	7	10	9	5	3	0	0	0
2	9	10	7	6	5	3	0	0	0
2	9	10	8	6	5	3	0	0	0
2	1	4	7	10	9	5	3	0	0
2	4	7	6	8	10	5	3	0	0
2	4	7	10	8	6	5	3	0	0
2	9	10	7	4	1	5	3	0	0
2	1	4	7	6	8	10	5	3	0
2	1	4	7	10	8	6	5	3	0
2	4	7	6	8	10	9	5	3	0
2	1	4	7	6	8	10	9	5	3
2	9	10	8	6	7	4	1	5	3

Bar graph plot for gain VS routes for (2, 3) pair

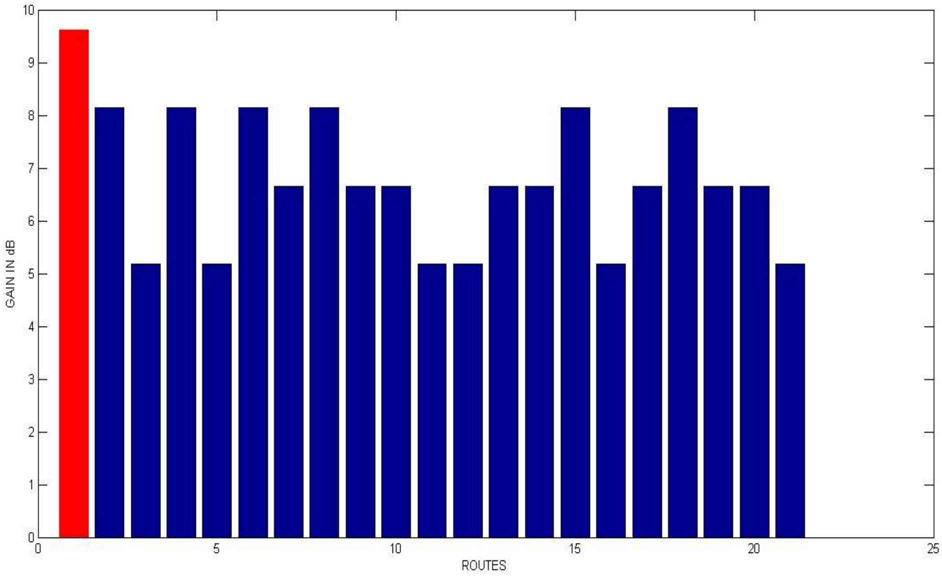


Fig 4.3 unsorted gain for source=2 and destination=3

Sorted bar graph for gain VS routes for (2, 3) pair

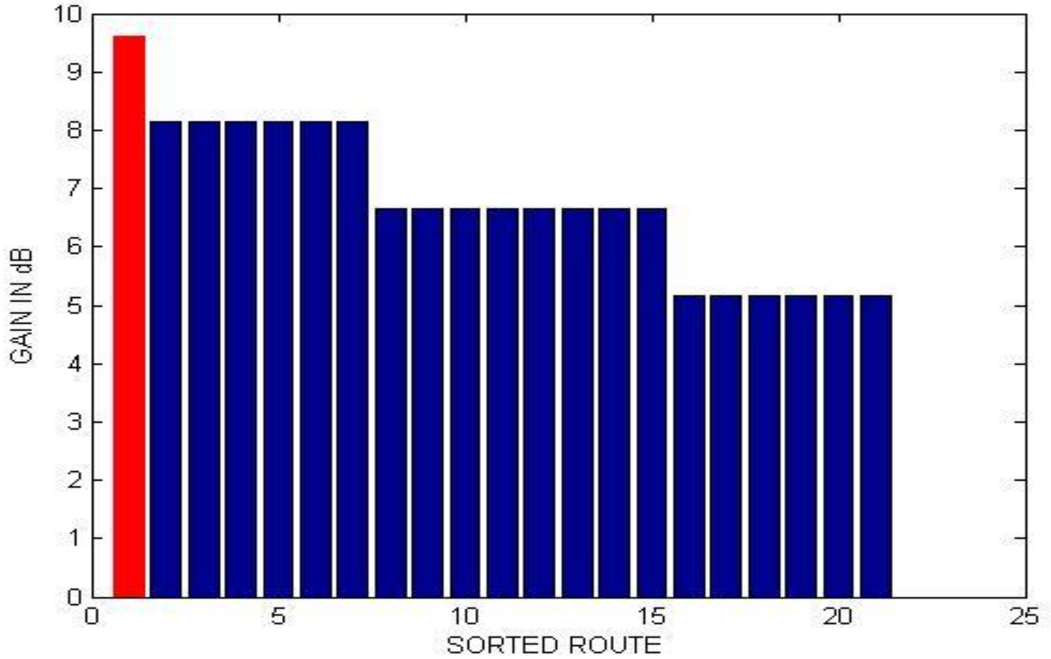


Fig4.4 sorted bar graph for source=2 and destination=3

Bar graph for gain VS routes for (3, 4) pair

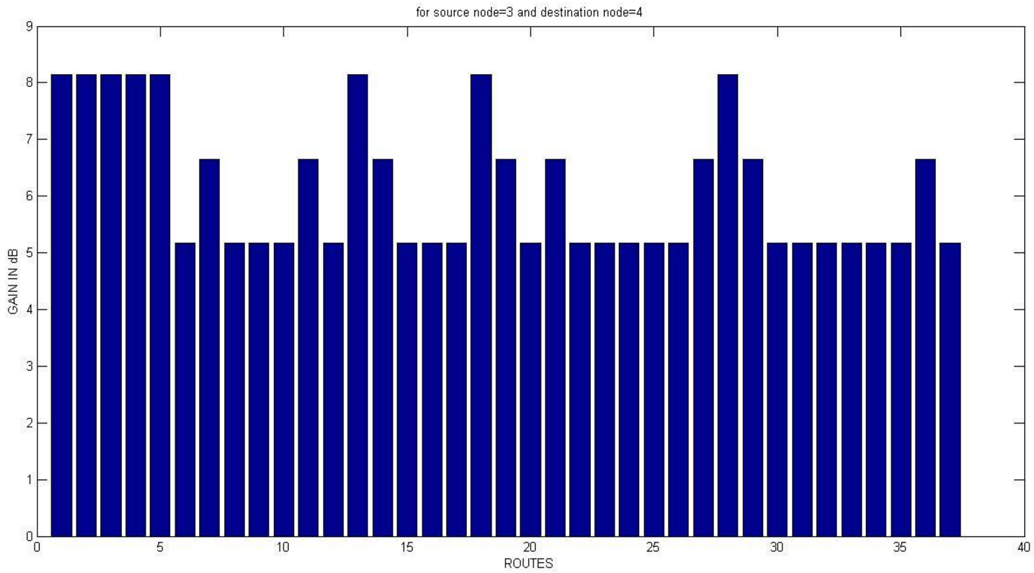


Fig 4.5 bar graph for source=3 and destination=4

Sorted Bar graph for gain VS routes for (3,4) pair

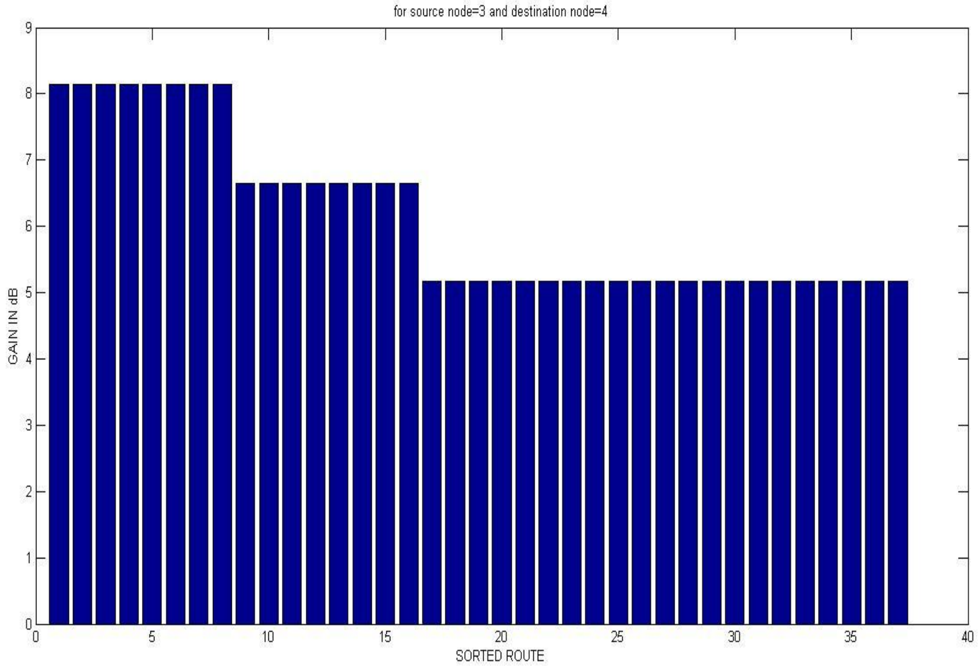


Fig 4.6 sorted bar graph for source=3 and destination=4

In bar plot, gain VS all the routes has been taken. Route with maximum gain has been highlighted and taken to be the best optimum path between that source-destination pair.

4.3 Optical Virtual Private Network

VPN is a virtual circuit (VC) and can be characterized as an end to end association with an arrangement of nature of transmission parameters connected with it [16]. VPN administrations are vital in current systems. It is a virtual system since it is not manufactured physically and independently, but rather it is just a part and assigned piece of assets of an open system of a supplier [17]. It is private since it serves a close gathering of clients. It performs RWA capacity of taking information from its source and conveying to its destination. The IP based VPN can understand just point-to-point association situated administrations [18]. To give propelled administrations, the IP based system administration supplier may require: i) adaptable control and management, and ii) Multiple clients/systems settlement. Keeping in mind the end goal to understand the afore mentioned highlights, a few proposition are said. Qualities of OVPN can be outlined as: i) integration is limited inside a situated of clients, where network implies information plane network and additionally control and administration plane connectivity and control, ii) administration data for one OVPN is never educated to whatever is left of OVPNs, and ii) some level of control and administration functionalities is given to clients, where clients can reconfigure system topology, and in addition mirror their own operational strategy over the supplier's optical system for all intents and purposes committed to every OVPN. These functionalities change relying upon administration prerequisites from client.

VPN can be named client edge (CE) based, system based, , supplier provisioned, association arranged, clients provisioned, connectionless situated, layer 1 VPN, layer 2 VPN and layer 3 VPN . The necessity of OVPN can be arranged with reference to : i) administration plane, for example, detail of strategy and system segment data, and ii) control plane, for example, light path setup, association appeal and topology data and so forth.

A general approach using a flowchart for PLIs based RWA calculation [8] is indicated in Figure 4.7. When all is said in done, the RWA block is in charge of light path setting up.

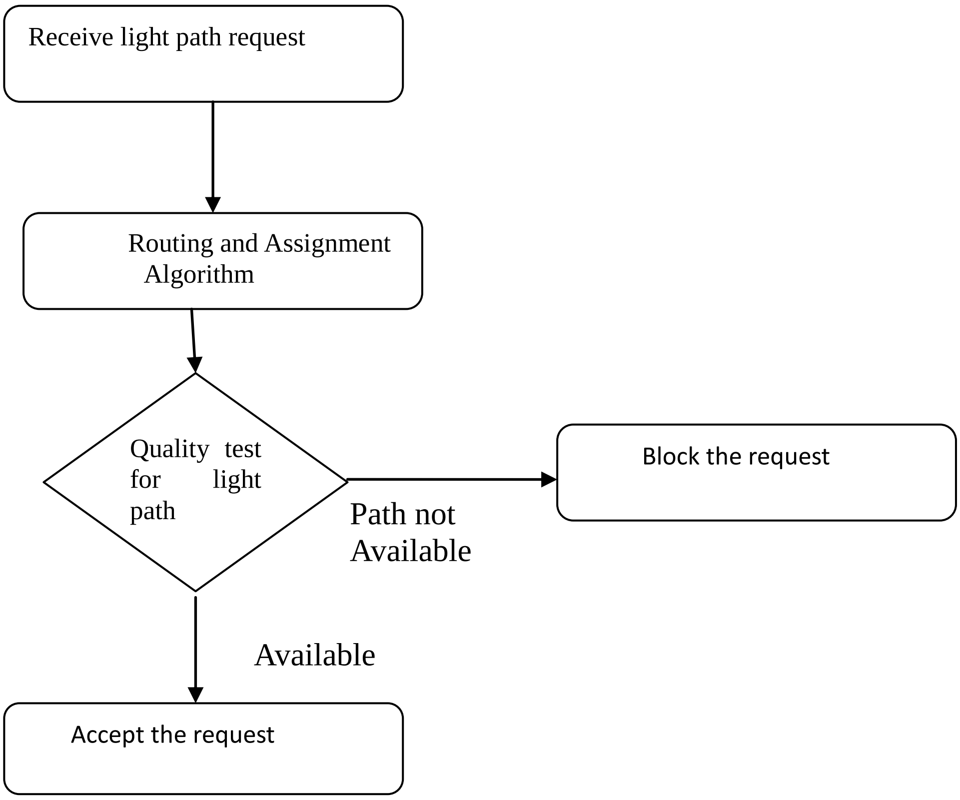


Fig4.7 A general flowchart for RWA algorithm

4.4Routing and Wavelength Assignment

RWA implies the methodology of making relationship between a source-destination consolidate and distributing wavelength to it. In a matter of seconds a-days in WDM/DWDM framework, a lone fiber can oblige up to 120 wavelengths and foreseen that would augment in future. The objective of RWA count is to fulfill the best possible execution inside the limits of the physical necessities. It is known not NP-complete, in this way it is normally had a tendency to by a two-stage approach: First, finding a relationship for a source-destination pair using a guiding methodology, and second, selecting of a free wavelength on the picked affiliation using a wavelength undertaking (WA) estimation.

4.5Different Routing Technique

In this following section many important routing techniques are being discussed.

Fixed Routing technique (FR): It is a technique where one single light path is computed for given source-destination pair [13]. This is very simple process and along with that as less number of light paths are available within a network, then blocking probability that is calculated for a connection request become high.

Fixed Alternate Routing technique (FAR): In this type, various connections alternatively are being calculated online when a source destination pair is given as input in FAR [14, 15]. After that these connections calculated are being arranged on the basis of some priority. In general the shortest path connection is considered to be the most prioritized 1. In certain other cases, where links are available in a route, that number of links can be taken as criteria for prioritizing paths.Whenever a request for connection arrives, at that moment the node given as source searches for connection to the destination given as long as it is able to find a connection between those pairs with an available wavelength for establishment of connection. If in any case connection cannot be available, then at that instant connection request is blocked. This type of technique for routing actually provides an alternate connection for a connection request that has been made that is why no problem of link failure. FAR method is more reliable as compared with FR for reducing blocking probability.

Adaptive Routing technique (AR) [20]: In this technique, the connections are being calculated online that depends on state as well as availability of resources in a network [12]. In this type, a connection between a source and a destination is adapted depending on various factors like the network state and shortest connection dynamically. While a request for connection is being made, the shortest connection in between the source and destination is calculated. If possibly more than 1 connections having same distances present, then in that case the route can be randomly selected after this if no connection is then the request would be blocked. This type of technique is considered to be the most efficient technique for routing with in a WDM/DWDM network. In the thesis, the idea of AR technique has been followed.

4.6 Computation of All Possible Connections

To calculate all possible OVPNCs, we have taken the depth first search algorithm which was used in traditional days [11]. In general DFS algorithm was NP-Complete for computing all types of possible paths, by taking in to account multiple parameters. Here for this computation I have used single parameter i.e., path gain.

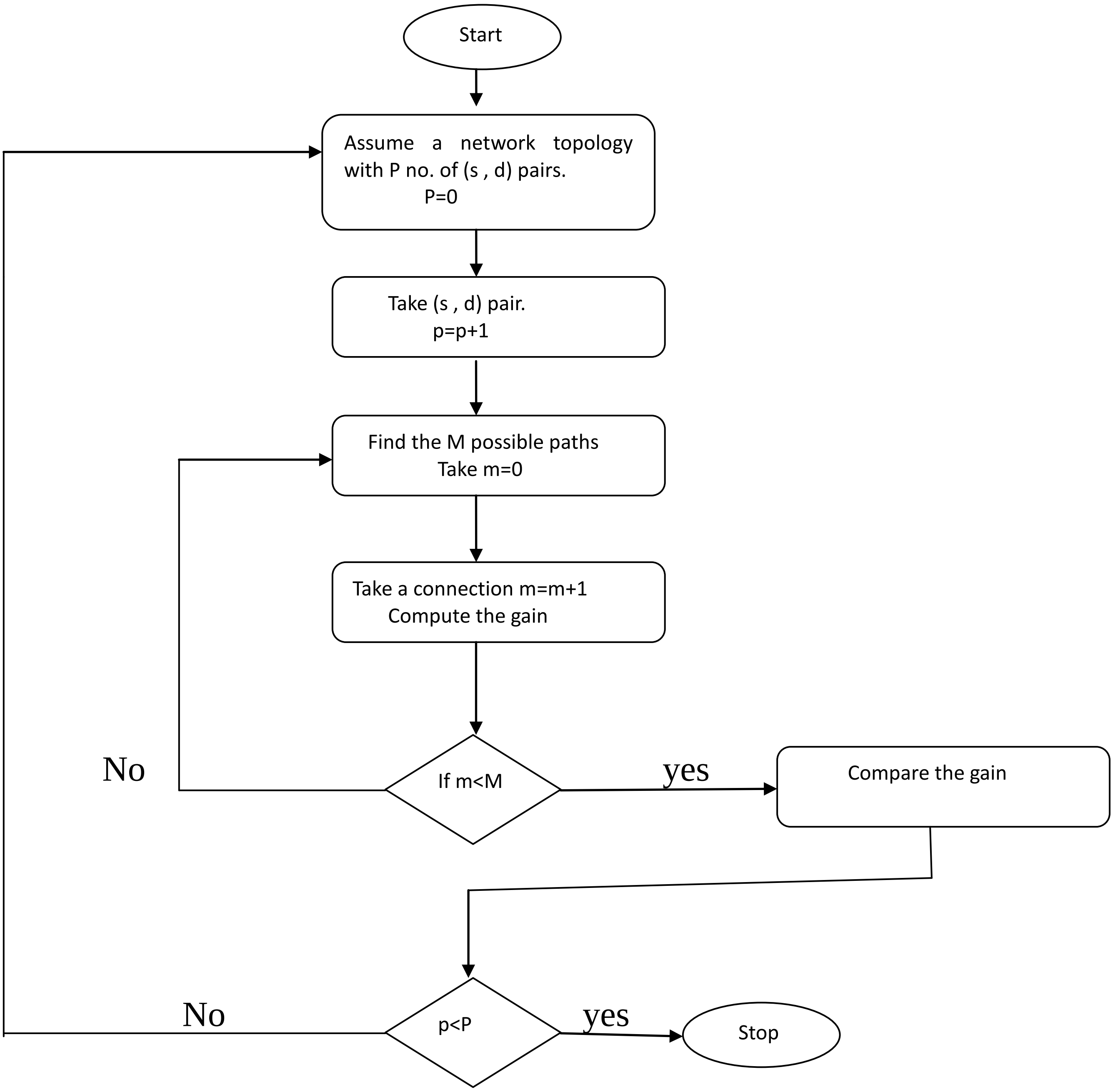


Fig 4.8 Flow chart for computation of gain in a WDM network

4.7Blocking Probability Calculation

4.7.1 Introduction

Wavelength-routed optical networks (WRON) can be considered as an alternative to the use of traditionally used electrically switched optical networks as they increase flexibility, network throughput. They also provide cost-efficient communication which is reliable over long distance. In these types of networks, nodes, for example optical cross-connects (OXC) and Optical Add-Drop Multiplex (OADM), are interconnected via fibre links which have multiple wavelengths. They additionally have neighborhood ports with coordinated between face with the Internet convention (IP) or the multiprotocol name exchanging (MPLS) routes. Another connection requires the routing and wavelength assignment (RWA) protocol to set up a light path between the source and destination hubs. In the event that there is no route between the sources to destination hubs with a wavelength accessible in every connection of the route, the association solicitation is blocked.

Thus, the blocking probability is one of the primary parameters that have been utilized to assess the execution of WRON in a few sorts of situations. In any case, it is hard to compute the accurate hypothetical blocking likelihood in optical systems, since the precise movement stack on every connection is obscure and relies on upon variables, for example, network topology and number of wavelengths. Another acknowledged system to accomplish the blocking probability in optical networks is the discrete event simulation that is a capable device to assess the effect of different systems parameters that are not simple to model, for example, physical layer and quality of transmission (QOT) parameters. However, in the meantime, the discrete event simulation exhibits a hard computational expense, since relying upon the reproductions situations, the passed time to accomplish the outcomes can be high. In addition, even the discrete event simulation must have a reference result to be defied with so as to be accepted.

Here a new model presented which can accurately calculate the blocking probability in wavelength-routed optical networks. The proposed method utilizes a link/ node reliance system in the multi wavelength optical network connections to ensure a relationship model to assess the blocking execution. This methodology shows extremely intriguing results to gauge the blocking probability for distinctive optical network situations. Taking into account the traffic profile (or traffic matrix)) and network topology, the blocking probability can be evaluated as a function of the traffic characteristics such as the wavelength assignment algorithm, the routing strategy, the wavelength conversion capability, the placement of wavelength converts, and quality of transmission (QoT) of the light paths.

The highlight that the same wavelength ought to be relegated to all links along a way, if there is no wavelength transformation in the hubs, is a key point in the investigative models for processing blocking probability in WRON. In the first place First-fit wavelength task calculation has been thought of it as, was explored that analytical models for calculating the blocking probability. The utilization of full-range or constrained extent wavelength converters can diminish the blocking probability because of the wavelength progression constraint. A few works have demonstrated that the blocking execution of restricted extent wavelength converters fit for changing to a small number of nearby wavelengths can nearly surmised that of full-range wavelength converters. Accordingly, arrangement of wavelength converters is additionally another viewpoint that can be essential in the optical network blocking execution. The issue is of discovering ideal position of wavelength converters, as far as blocking execution, has been explored. Here, it has been exhibited that sparse wavelength change could accomplish a blocking performance near to the one accomplished by full wavelength transformation.

The aim is to provide an Interactive Matrix Methodology (IMM)[10] that gives out an precise estimation of blocking probability in WRON taking into account that the link blocking events are correlated. The proposed link/node-reliance method considers the reliance among all connections and hubs in the system (not just for connections and hubs in a path or route). IMM introduces exceptionally precise results for a few optical networks situations and with low time complexity. Besides, not quite the same as different works, this new technique can be utilized as a part of optical networks situations with a number of wavelengths on every connection, and to register the estimative of blocking probabilities in every node. IMM is additionally appropriate in the low load regions and with certain numbers of wavelength, where other methods ought not to be utilized.

4.7.2Assumptions and notations

- The call requests between the source and the destination node arrive at the source in accordance of a Poisson process having a rate which is dependent on the source–destination pair.
- The holding time for a call is presumed to be exponentially distributed [10].
- There is a uniform distribution between the source and the destination edge nodes.

- It is also assumed that the Shortest Path algorithm (SP) (fixed routing algorithm) chooses a route between each pair of nodes.
- It is assumed that a call occupies the entire bandwidth of a particular wavelength, and therefore there are no sub wavelength processing methods, for example, traffic add/drop and multiplexing.
- A wavelength matrix Λ represents the network resources, and number of wavelengths on each link between nodes i and j is given by Λ (i, j).
- Wavelength possession in fibres and links are independent.
- If a connection is blocked, it is dropped immediately.
- A WRON with a capricious topology is considered.
- There is an association between loads among all links and nodes. Link blocking events are correlated as well.
- Λ is the wavelength matrix and the number of wavelengths on each link between nodes i and j is given by Λ (i, j).
- T is a n x n matrix, where n represents the number of network nodes and each nonzero element T (i,j) is the number of routes supported by each of the links which are between nodes i and j; M is a three-dimensional cubic matrix M, with size n, which contains the portions of traffic arriving from node i at node k that will be routed to the node j (k is the next node after j).
- P is the traffic load matrix;
- G is an n x n matrix which represents the traffic which is generated on each node j with node k being the next node (and it is considered that there is a link between the nodes j and k).

If p_{net} is the total load given to the network then load matrix *p* can be calculated as:-

$$\mathbf{p = p_{net} / \sum^{n}_{i=1} \sum^{n}_{j=1} T\,(i,\,j)} * \mathrm{T} \qquad (1)$$

Where *T* stands for an matrix of size n×n, where n stands for the number of network nodes and each nonzero element T (i,j)[10] is the number of routes supported by each link between node i and node j.

The initial blocking probability matrix can be calculated for all the network links using Erlang-B formula

$$\mathbf{B(i,j) = (\,p(i,j)^{w}\ /\ w!\,)\ /(\sum^{w}_{s=0}\ P(i,j)^{s}\ /\ s!\,)} \qquad \mathbf{(2)}$$

Where w stands for the number of wavelengths on each link and *P* implies to the load matrix.

Later on it has been observed that the traffic load arriving at *j* is dependent on traffic loads of all adjacent links and loads .That is why the algorithm takes into account the contribution of all links and nodes while calculating blocking probability for a node.

$$\mathbf{B_{node}(i) = \sum^{n}_{j=1} B(i,j) \,.\, T(i,j) \,/\, \sum^{n}_{j=1} T(i,j)} \qquad \mathbf{(3)}$$

4.7.3 The Interactive Matrix Methodology

An IMM[10] is acquainted as a technique with executing a connection/hub dependence model which is situated in redesigning the activity load commitments from all the connections and hubs in the entire system, and not simply using the connections as a piece of a given way or course. The proposed IMM the uses introductory P, as well as utilizations redesigned renditions of the worth ascertained. In this way, all the activity which touches base at hub j from the hub i must be dealt with at hub j in two unique ways: (i) if certain given bit of the movement has j as the destination edge hub, it is not utilized and this won't contribute for the yield movement leaving the hub j; (ii) when j is considered as a steering hub for a bit of activity landing from hub i, this activity is separated as per the characterized courses between its yield joins. Along these lines, a three-dimensional cubic framework which is M, having a size n, can likewise be characterized for the system. M contains the segments of movement landing at hub j from hub i which will be directed through hub k. It can be effectively seen that M will have nonzero components just if there are connections from hub i to hub j furthermore from hub j to hub k. The activity which is dropped by the separate hub won't have any commitment to the yield loads. Likewise, the movement load which lands at hub k from hub j will have the commitments of every last one of hubs i which interface with j, alongside the activity created in hub j which is directed through the hub k. This happens just if j is an edge hub (wellspring of activity).

The activity which is produced on every hub j which has hub k as the following hub (and it is viewed as that there is a connection between the hubs j and k) will be spoken to by a G network. Thus, the component G (j,k) is the part of activity created by hub j having k as the following hub. When the connection load P (i,j) can be effortlessly figured by T(i,j) and it additionally creates the blocking likelihood B(i,j), one can redesign the framework M, and subsequently in the procedure producing the frameworks Mu and Tu, respectively. These grids can be utilized over and over to figure redesigned adaptations of P, Pu and another overhauled blocking likelihood network Bu. A helper Boolean framework A, with the same size of B and with all components equivalent to TRUE, aside from components A(i,j) where there is a connection in the middle of i and j, that are situated to FALSE, is utilized to intrude on the execution of this calculation. Consequently, the components of An are situated to TRUE when the rate contrasts between B (i,j) and Bu(i,j) are beneath a little edge ϵ. The methodology will stop unquestionably when all the components of An are TRUE

4.8 Simulation Results and Discussions

Variations of T-matrix

Here various cases have been taken by taking different gain margin like-without margin,6-dB margin, 8dB margin and 10dB margin. Followings are the possible T-matrices.

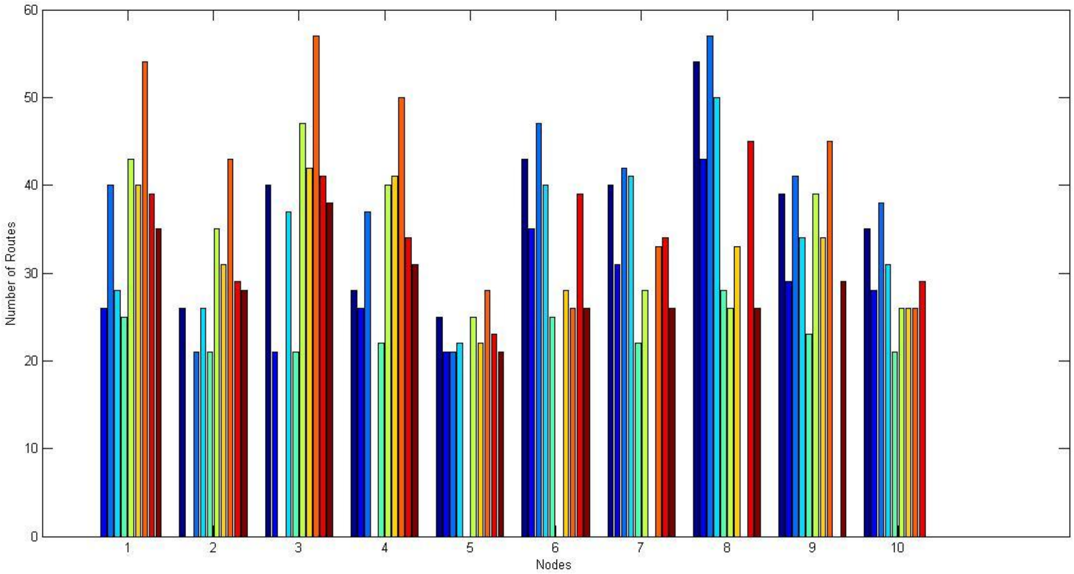


Fig 4.9 No of routes VS Nodes on the basis of gain

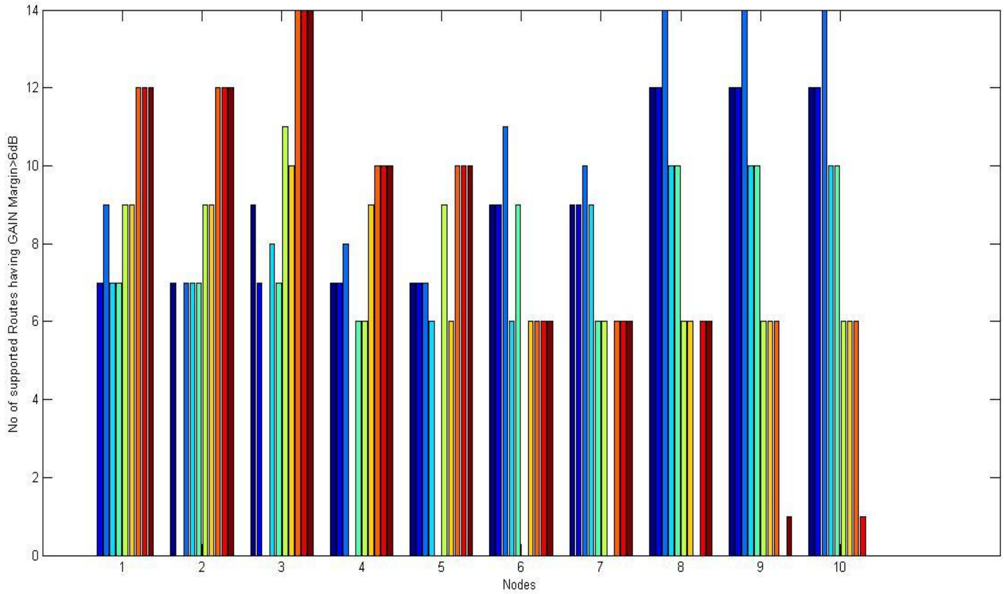


Fig 4.10 No of routes VS Nodes when gain margin>6dB

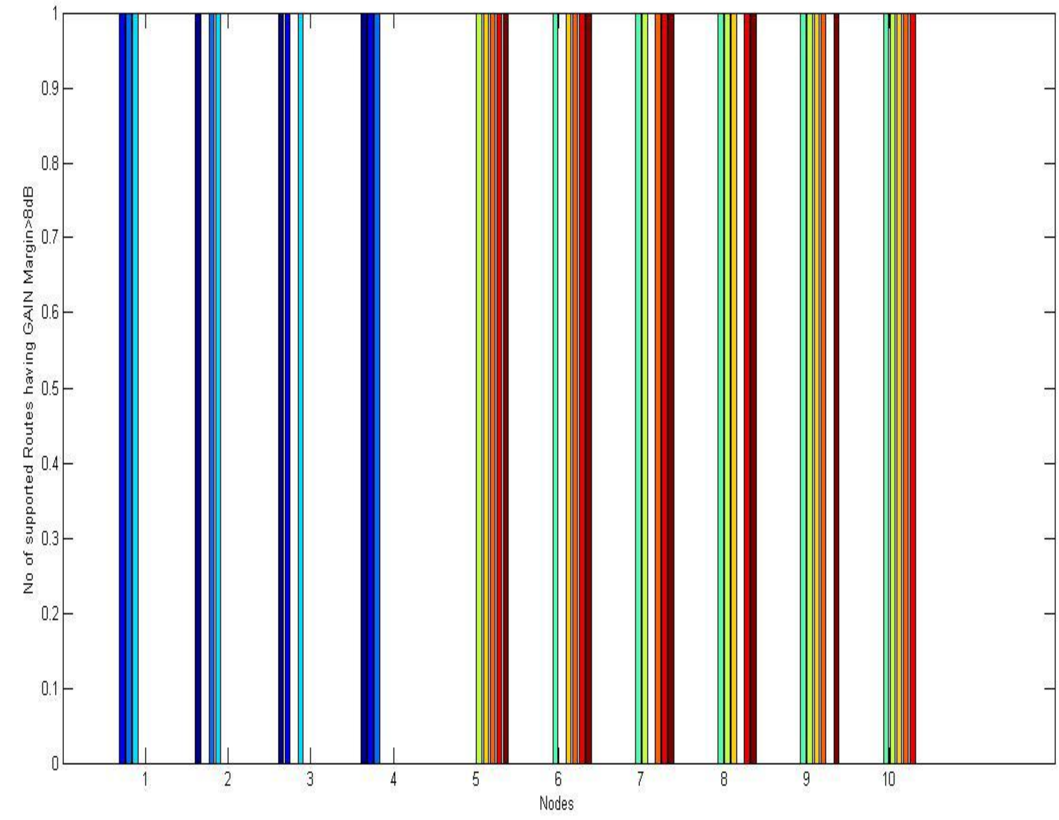


Fig 4.11 No of routes VS Nodes for Gain margin>8dB

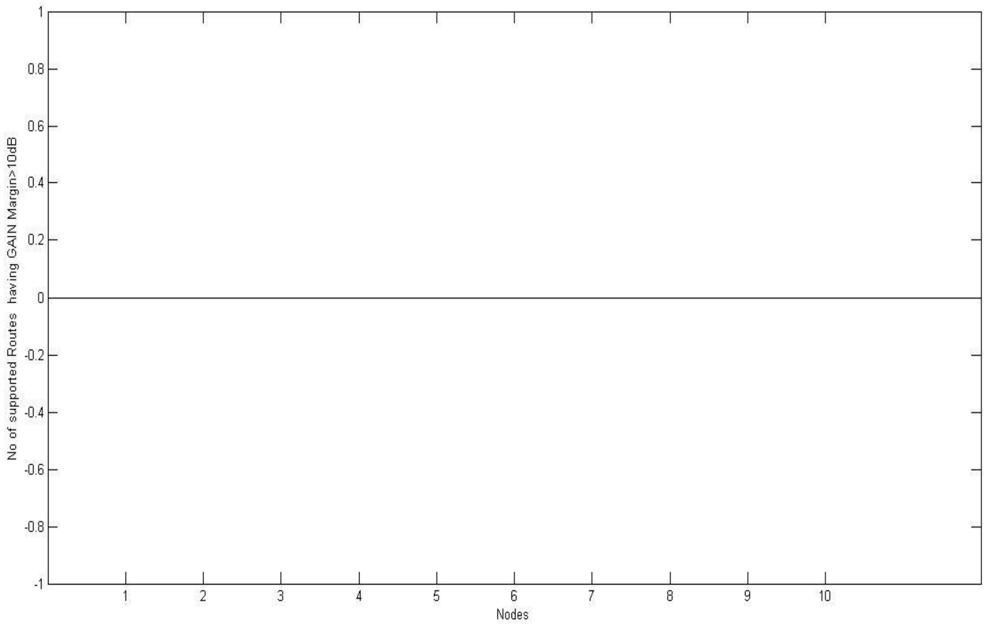


Fig 4.12 No of routes VS Nodes for Gain margin>10dB

Blocking Probability Calculation

By using the formula of blocking probability of nodes, here using different T-matrices blocking probability VS nodes has been calculated .How variations in no of wavelength and gain margin affects blocking probability that has been observed from the following graphs.

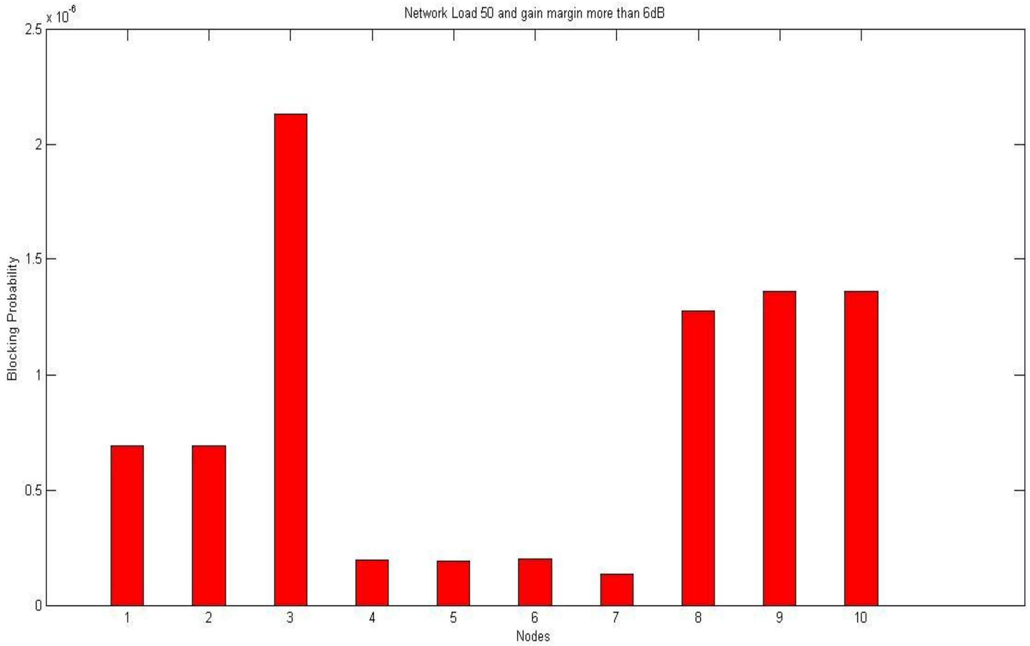


Fig 4.13 Blocking probability VS Nodes for load=50E, gain >6dB

No of wavelength=8

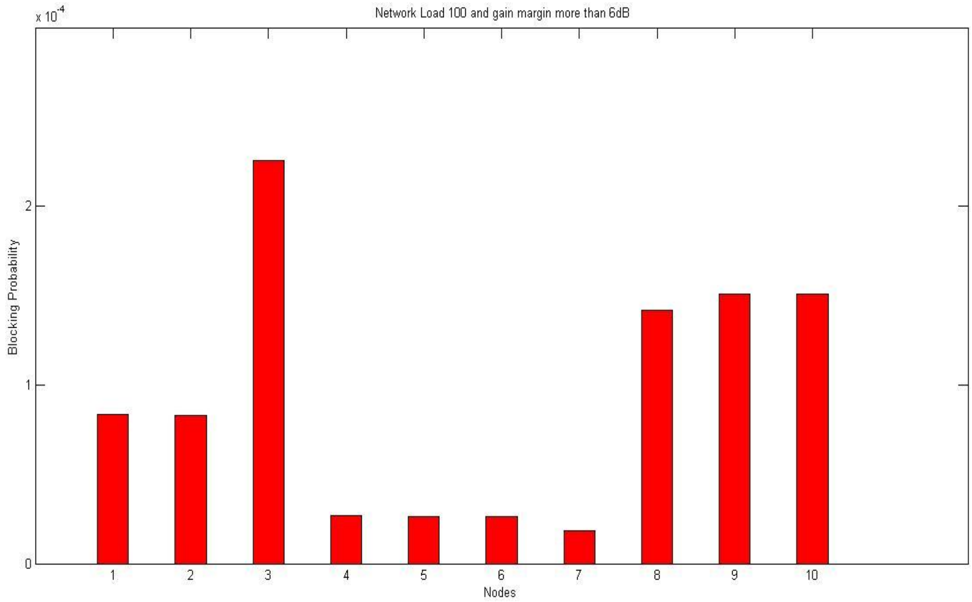


Fig 4.14Blocking probability VS Nodes for load=100E, gain >6dB

No of wavelength=8

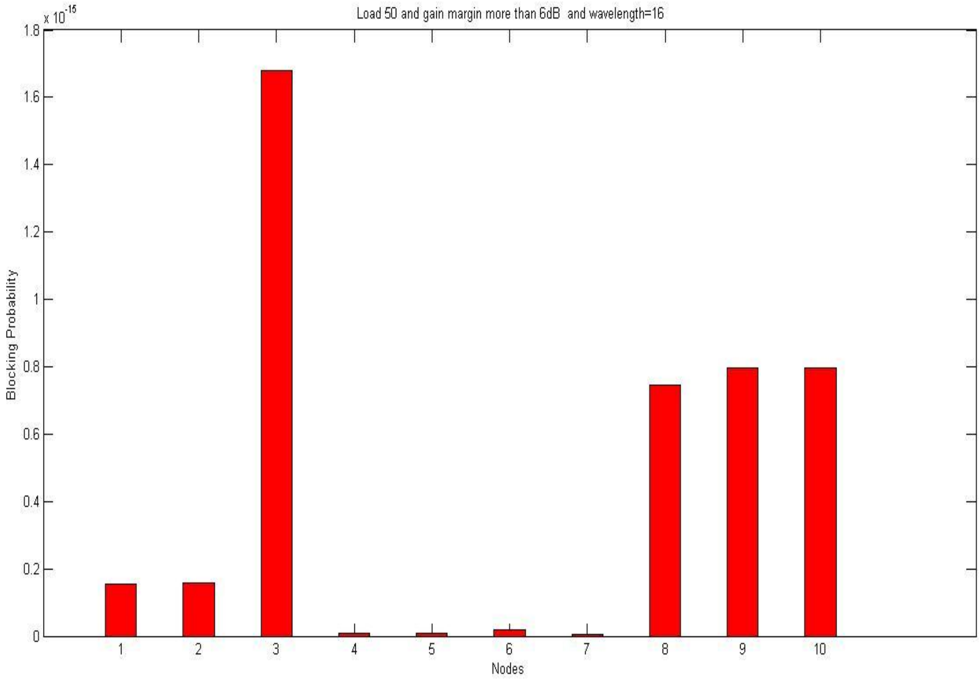


Fig 4.15 Blocking probability VS Nodes for load=50E, gain >6dB

No of wavelength=16

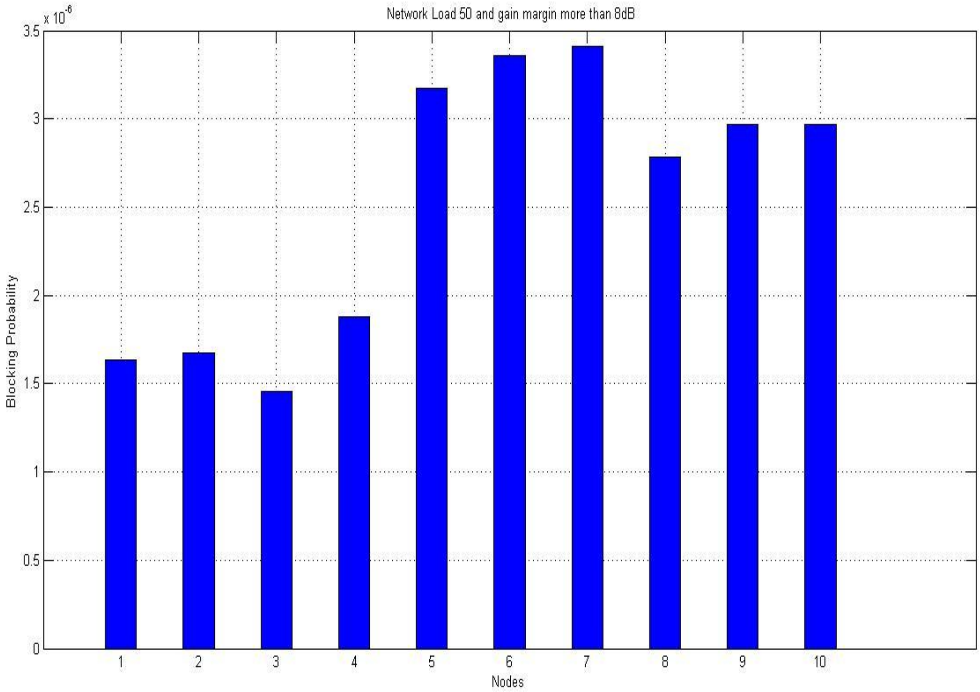


Fig 4.16 Blocking probability VS Nodes for load=50E, gain >8dB

No of wavelength=8

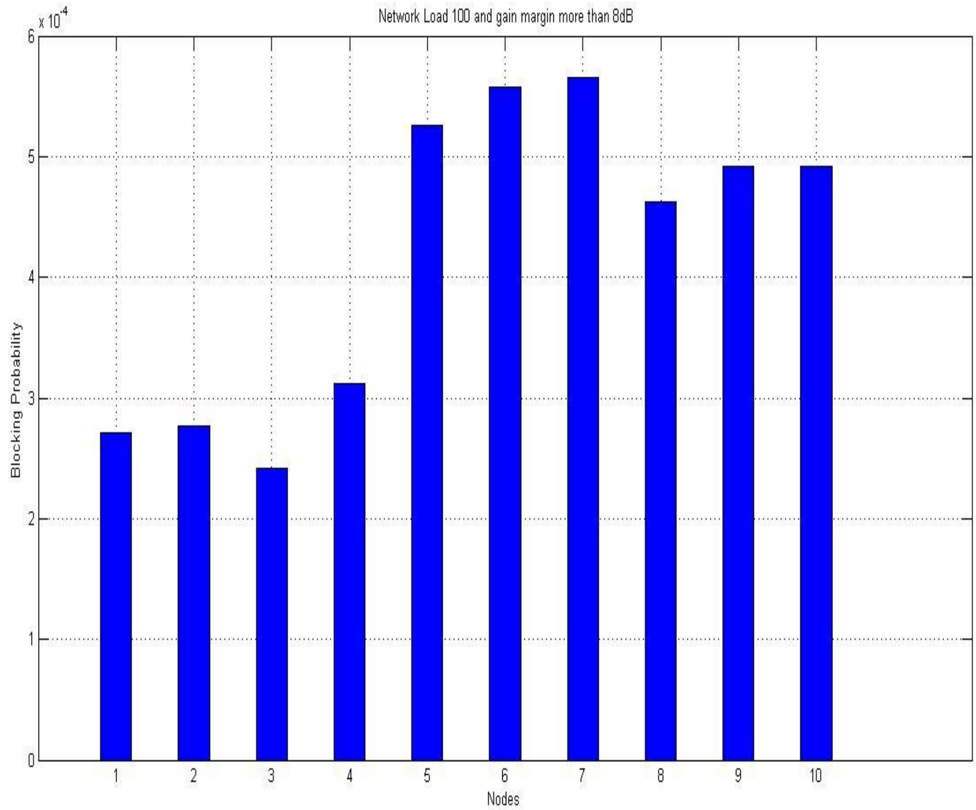


Fig 4.17 Blocking probability VS Nodes for load=100E, gain >8dB
No of wavelength=8

4.9 Conclusion

- Blocking probability increases as the load increases from 50E to 100E.
- Blocking probability decreases as the number of wavelength assigned increases from 8 to 16.
- When gain margin increases from 6dB to 8dB, number of routes relatively decreases .So due to less availability of routes, blocking probability increases.

Bibliography

[1] Prachi Shukla, Kanwar Preet Kaur *"Performance Analysis of EDFA for different Pumping Configurations at High Data Rate* "International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-2, Issue-5, June 2013.

[2] G.P. Agarwal, "*Fibre-Optic Communication Systems"*, John Wiley& Sons, New York, 1997

[3] M.N. Islam," *Raman Amplifiers for Telecommunications 1*", Physical principles, Springer, 2004

[4] **"***Performance evaluation of EDFA, RAMAN and SOA optical amplifier for WDM systems* "by Simranjit Singha, Amanpreet Singh , R.S. Kalera, Department of Electronics and Communication Engineering, Thapar University Patiala, India

[5] M. Pal, M.C. Paul, A. Dhar, A. Pal, R. Sen, K. dasgupta and S.K. Bhadra,*'' Investigation of the optical gain and noise figure for multichannel amplification in EDFA under optimized pump conditio*n", pp.407-412, Elsevier, 2007.

[6] J. Gowar,'' *Optical Communication Systems*", Second Edition, 2003.

[7] Yuhong Kang Roger H. Stolen, Chair, Ira Jacobs, Ahmad Safaai-Jazi" *Calculations and Measurements of Raman Gain Coefficients of Different Fibre Types"* December 9, 2002 Blacksburg, Virginia.

[8] Hani j. Kbashi, Mohammed A. Hameed, Amer A. "*Mathematical Model of Amplified Stimulated Raman Scattering and Fibre Raman Amplifier"* Ramadan University of Baghdad, College of Science,2011**.**

[9] F. D. B. Mahad and A. S. B. Mohd Supa,'' *EDFA Gain Optimization for WDM System*", vol. 11, no. 1, pp. 34-37, ELEKTRIKA, 2009.

[10] Luiz H.Bonani, Iguatemi E.Fonseca" Estimating the blocking probability in wavelength-routed optical ", *optical switching and networking* 10(2013)430-438,4th July, 2013

[11] “*Analytical characterization of optical power and noise figure of forward pumped Raman amplifiers*” Malin Premaratne ,Advanced Computing and Simulation Laboratory (AXL) *Department of Electrical and Computer Systems Engineering*, Monash University, Clayton 3800 Victoria, Australia.

[13] H. Zang and J. P. Jue, “A review of routing and wavelength assignment approaches for wave-length routed optical WDM networks,” *Optical Network Magazine*, vol. 1, no. 1, pp. 47–60, January 2000

[14] R. Ramamurthy and B. Mukherjee, “Fixed-alternate routing and wavelength conversion in wavelength-routed optical networks,” *IEEE/ACM Transactions on Networking*, vol. 10, no. 3, 351–367, 2002

[15] V. Saminadan and M. Meenakshi, “In-band crosstalk performance of WDM optical networks under diﬀerent routing and wavelength assignment algorithms,” in *Lecture Notes in Computer Science, Springer Berlin Heidelberg*, vol. 3741, December 2005, pp. 159–170

[16] R. S. Kaler,” *Simulation of 16 × 10 Gb/s WDM system based on optical amplifiers at different transmission distance and dispersion*”, Elsevier, 2011.

[17] A. H. Beshr, M. H. Aly and A.K. AboulSeoud,” *Different Pump Configurations for Discrete Raman Amplifier”,* journal of electrical & electronics engineering, vol 2, Issue 11, November 2011.

[18] Z. Li, Y.J. Wen, C. Yu, W. Rong, Y. Wang and T. H. Cheng,” *Optimizing Raman/EDFA hybrid amplifier based on dual order stimulated Raman scattering of a single pump”* , Optical Society of America, 2006.

[19] “*Exact Mathematical Model for Dual-Pump Distributed Fibre Raman Amplifier* “Haitham S. Mostafa and Moustafa H. Aly, Member OSA College of Engineering and Technology, *Arab Academy for Science*, Technology and Maritime Transport, Alexandria, Egypt.

[20] G. Poo and A. Ding, “Blocking performance analysis on adaptive routing over WDM networks with finite wavelength conversion capability,” *Photonic Network Communications*, vol.12,no.2 ,pp.211–218,September2006.